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This study reviews and integrates scientific and technical information on ocean disposal to develop concepts for monitoring and regulating this practice. The objective is to provide, as a basis for EPA's future regulatory decisions, a rationale that considers ocean disposal in terms both of the need for ocean disposal, and of the capacity, agreed upon by the Environmental Protection Agency and the study group, involves the discharge of waste into one medium only--the ocean. The Marine Protection Research and Sanctuaries Act of 1972 and the Federal Water Pollution Control Act Amendments of 1972 are similar in that they regulate ocean disposal as an isolated waste discharge problem specific to the water medium.

The present report is addressed to the Environmental Protection Agency and Congress, but it may also be of interest to members of other federal, state, and local governments, to the scientific community, and to the public at large. For that reason, the report synthesizes broad principles in a format that will be instructive for those who must make policy decisions about disposal in the ocean.

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DISPOSAL IN THE MARINE ENVIRONMENT:

AN OCEANOGRAPHIC ASSESSMENT

An Analytical Study for the
U.S. Environmental Protection Agency

A report of the Ocean Disposal Study Steering Committee prepared under the auspices of the Ocean Affairs Board's Ocean Science Committee in the Commission on Natural Resources of the National Research Council

National Academy of Sciences
Washington, D.C. 1976

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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FOREWORD

Handling the residual materials from an industrialized society requires careful evaluation of a variety of options. To be effective, the evaluation must be based on scientific and technical realities and should include economic and social considerations. Ocean disposal, the subject of this report, is only one of these options. The others, broadly defined, include reuse or resource recovery, disposal on land, disposal in the air, and disposal in fresh waters. Each of these options has been in use for many years, but it was not until the relatively recent public awareness of possible undesirable effects of placing residual materials in the environment that increasing pressure developed to bring under government control this aspect of industrialized living.

The legislative response to the public's desire for the control of pollution has been the formulation of regulations which independently control disposal practices as they affect the quality of air and water. For ocean disposal, the legislation (PL 92-500 and PL 92-532) spells out a number of separate goals and mechanisms, for marine and fresh waters, to be implemented by the Environmental Protection Agency. This media-specific arrangement implies that the separate consideration of each option (in this case, ocean disposal) can achieve the necessary balance between the public's desire for protection of the total environment and the waste disposal demands of an industrialized society. Such is clearly not the case.

The legislative and regulatory framework should incorporate a mechanism that evaluates all the options (air, land, and water) for disposal of a residual material and seeks a balanced and equitable allocation of costs and benefits. The emphasis of the current regulatory framework may, in practice, overprotect one sector of the environment and transfer the residual disposal problem to another sector. A comprehensive framework would seek to avoid such transfer by making mandatory the initial evaluation of all options and effects. To the extent that the materials flow cycle cannot be closed by resource recovery, wastes must go somewhere. The ocean may in fact prove to be an attractive sink for some residuals after a thorough comparative study has been completed.

Awareness of this eventual need for systematic reorganization should not, however, be allowed to obscure the more immediate potential for improvement within the system as it now stands. This report, therefore, considers the scientific and technical aspects of ocean disposal problems as a basis for improving practices under existing regulations.

GORDON J.F. MacDONALD
Chairman
Commission on Natural Resources

DISPOSAL IN THE MARINE ENVIRONMENT:
AN OCEANOGRAPHIC ASSESSMENT

INTRODUCTION

BACKGROUND

The U.S. Congress has passed major legislation dealing with environmental problems, the nature and effects of which are matters of wide public concern. A study by the National Academy of Sciences on environmental decision making was funded under the Fiscal Year 1974 Appropriations Act for the U.S. Environmental Protection Agency (EPA). Several complementary studies were organized in response to that contract under the direction of the Commission on Natural Resources of the National Research Council (NRC). The entire study program is described in full in the First Annual Report of the Steering Committee for Analytical Studies for the U.S. Environmental Protection Agency (NAS 1975a).

The present study grew out of the concern of the Ocean Affairs Board (OAB) and its Ocean Science Committee (OSC) about ocean disposal problems. As one result of this concern, an ad hoc panel was formed by the OSC to examine the subject and organize a study. After discussions with the EPA, this panel organized the workshop that led to this report. The workshop was held at Woods Hole, Massachusetts, in September 1974, with approximately 70 scientists and engineers participating (See Appendix B). Observers from the EPA were also in attendance. The discussions and findings of the workshop provided direct and immediate assistance to the Agency in setting criteria for the selection and management of disposal sites. As a case study of the regulation of disposal of residuals to the ocean, however, this report illuminates complex issues facing the EPA, and forms a suitable component of the broader EPA Analytical Studies Program described above.

The original steering committee, along with some additional members, compiled and edited this report, which was subsequently reviewed in accordance with Academy procedures.

SCOPE AND OBJECTIVES

This study reviews and integrates scientific and technical information on ocean disposal to develop concepts for monitoring and regulating this practice. The objective is to provide, as a basis for EPA's future regulatory decisions, a rationale that considers ocean disposal in terms both of the need for ocean disposal, and of the capacity of the marine ecosystem to receive wastes. This objective, agreed upon by the Environmental Protection

Agency and the study group, involves the discharge of waste into one medium only--the ocean. The Marine Protection Research and Sanctuaries Act of 1972 and the Federal Water Pollution Control Act Amendments of 1972 are similar in that they regulate ocean disposal as an isolated waste discharge problem specific to the water medium.

Early in the preparation of this report, however, it became clear that the important issues associated with ocean disposal covered here would benefit from an evaluation of the management issues associated with waste discharge in fresh water, on land, or in the air. Therefore, a separate, complementary NRC report on municipal sewage treatment sludge disposal options is now being prepared to determine the most appropriate medium for this specific waste as an example of comprehensive management.

The present report is addressed to the Environmental Protection Agency and Congress, but it may also be of interest to members of other federal, state, and local governments, to the scientific community, and to the public at large. For that reason, the report synthesizes broad principles in a format that will be instructive for those who must make policy decisions about disposal in the ocean.

The report first describes the current legislation and regulations that form the background of the waste disposal problem. Next, it discusses the amount and properties of waste materials and the processes that affect their distribution and fate in the marine environment; these properties and processes form the general scientific constraints on alternatives for management. The system under which the Environmental Protection Agency currently operates is next evaluated through examination of desirable practices for site selection and site monitoring. The final section offers recommendations for further development of solutions to the problem of incorporating existing scientific information in the management of ocean disposal.

CHAPTER I

LEGISLATIVE BACKGROUND

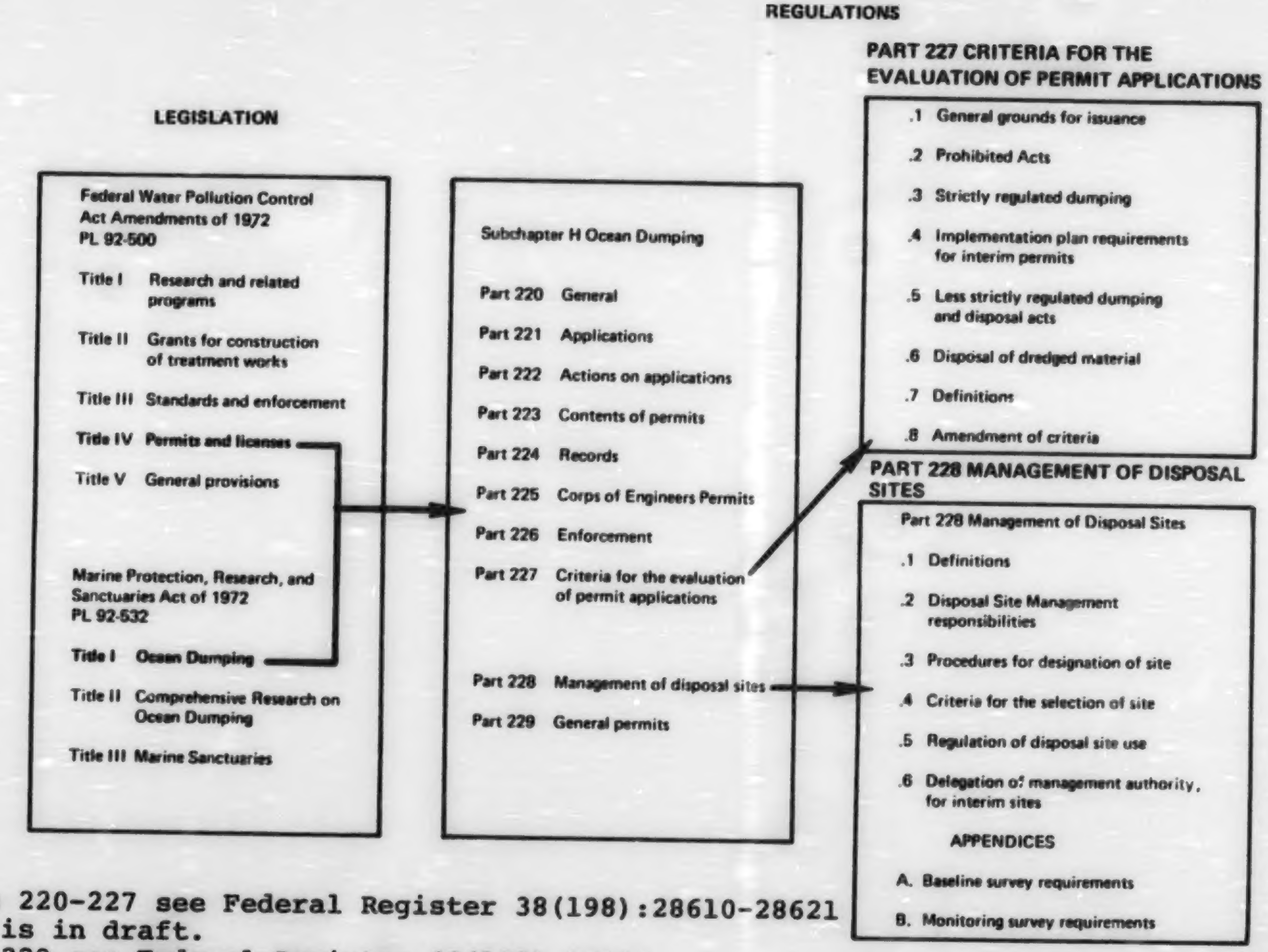
Federal legislation relating to waste disposal in the marine environment started with the Rivers and Harbors Act of 1899. A summary of that act and all the intervening legislation up to 1972 (Pararas-Carayannis 1973) indicates that environmental protection has only recently been considered as important to society. Before 1972, a lack of scientific standards in waste disposal legislation, as well as the exclusion from that legislation of several important practices, resulted in inadequate regulatory procedures. In 1970 these omissions, coupled with the need for a single oversight agency, such as the Environmental Protection Agency, formed a basis for legislation to control the process of ocean disposal (CEQ 1970).

The resultant legislation (Figure 1) provided for control of both pipe discharges (National Pollution Discharge Elimination System of PL 92-500) and material discharged from vessels (Ocean Dumping Section of PL 92-532). As shown, a common set of regulations applies to the administration of both programs. The specific language used indicates that a substantial number of decisions with respect to the ocean disposal management process have been made directly by Congress. For example, Title I of PL 92-532 prohibits ocean disposal of certain materials, establishes permit procedures, and places dredging permits under the control of the Corps of Engineers.

Currently, a uniform set of regulations (Figure 1) is used to control ocean pipe discharges (as called for in Title IV of PL 92-500) and vessel discharges (as called for in Title I of PL 92-532). The bold lines and print in Figure 1 indicate this relationship. Two of the parts which consider some of the scientific aspects of this regulatory approach are shown in greater detail. Part 227 defines criteria for the evaluation of permit applications and part 228 considers the management of disposal sites. Site selection and site monitoring, Chapters V and VI of this report, are an oceanographic assessment of some of the management issues noted in part 228.

FIGURE 1

Ocean Disposal Legislation and Regulations


REGULATIONS
LEGISLATION
Federal Water Pollution Control Act Amendments of 1972
PL 92-500
Title I Research and related programs
Title II Grants for construction of treatment works
Title III Standards and enforcement
Title IV Permits and licenses
Title V General provisions
Marine Protection, Research, and Sanctuaries Act of 1972
PL 92-532
Title I Ocean Dumping
Title II Comprehensive Research on Ocean Dumping
Title III Marine Sanctuaries
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For parts 220-227 see Federal Register 38(198):28610-28621
Part 228 is in draft.
For Part 229 see Federal Register 40(138) 30114

CHAPTER II

OCEAN DISPOSAL MATERIALS

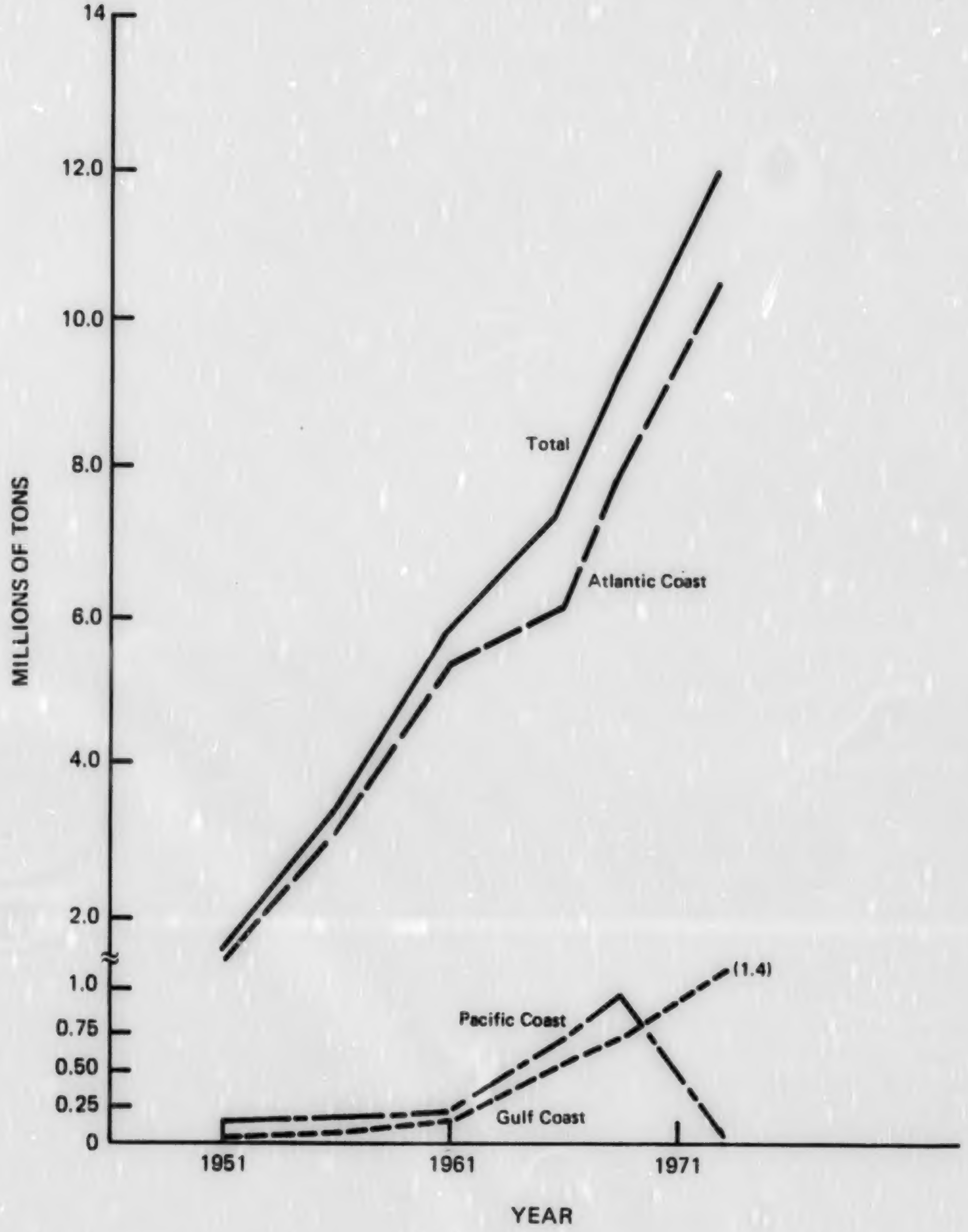
The amounts of materials and their properties are both part of the information necessary for evaluating the appropriateness of ocean disposal. This chapter's consideration of the amounts of materials introduced into the marine environment is divided among three categories: dredge spoil; materials disposed from ships and barges; and material discharged through pipes. Materials are defined in terms of major and minor constituents. The concluding sections of the chapter describe the physical and chemical properties of the materials, as well as some of the impacts they have had on the environment.

AMOUNTS

The materials traditionally emphasized in ocean disposal are dredge spoil, industrial wastes, sewage sludge, construction and demolition debris, solid wastes, explosives, and minor amounts of other categories. Industrial wastes include byproducts from a variety of processes including oil drilling, oil refining, waste acids, and other chemicals. Sewage effluent may contain 3 percent or less solids by weight while organic sludges produced by treatment often contain higher percentages of solids. Construction and demolition debris are various building materials. Solid wastes include garbage and refuse, as well as a variety of other materials. Other categories include radioactive materials, unsatisfactory or contaminated products, and byproducts of processes such as fermentation. Figure 2 shows the trends in use of the ocean as a disposal site for these materials on each of the U.S. coasts since 1951. For recent years the amounts of specific components discharged from vessels are indicated in Table 1. While the data are reported as absolute amounts, they are clearly not measured quantities, which would imply the careful weighing of each waste. Rather, these data are estimates of the amounts, and often the units are not carefully specified. In the future, methods of estimation should be made explicit to avoid ambiguities. The existing data indicate that, except for the Pacific Coast, the total amounts of these materials placed in the ocean increased through 1973; thus, enactment of the 1972 legislation implementing alternatives to ocean dumping did not stem the continuing increase in use of the ocean for disposal.

FIGURE 2

Ocean Disposal Exclusive of Dredge Spoil and Pipe Discharge



Source: CEQ (1970:9); EPA (1974b:27)

TABLE 1

Vessel Discharge Ocean Disposal: Types and Amounts, 1968, 1973, 1974

	ATLANTIC			GULF			PACIFIC			TOTAL		
WASTE TYPE	1968	1973	1974	1968	1973	1974	1968	1973	1974	1968	1973	1974
Industrial Waste	3,013,200	3,997,100	4,767,000	696,000	1,408,000	950,000	981,300	0	0	4,690,500	5,405,100	5,717,000
Sewage Sludge	4,477,000	5,429,400	5,676,000	0	0	0	0	0	0	4,477,000	5,429,400	5,676,000
Construction & Demolition Debris	574,000	1,161,000	2,242,000	0	0	0	0	0	0	574,000	1,161,000	2,242,000
Solid Waste	0	0	0	0	0	0	26,000	240	200	26,000	240	200
Explosives	15,200	0	0	0	0	0	0	0	0	15,200	0	0
TOTAL	8,079,400	10,587,500	12,685,000	696,000	1,408,000	950,000	1,007,300	240	200	9,782,700	11,995,740	13,635,200

Source: CEQ (1970:3); EPA (1975:24)

Materials Disposed from Ships and Barges

Next to dredge spoil, barge-dumped sewage sludge is the major waste type released along the Atlantic Coast; industrial wastes are predominant along the Gulf Coast; and sewage discharge by pipeline is characteristic of the Pacific Coast (Figure 2, Table 1). Other reports have treated this geographic variability in more detail (CEQ 1970, IEC 1973, NAS 1975b).

Materials Discharged Through Pipes

A variety of materials enters the marine environment through pipe discharges. This method of waste disposal is used in many areas, but Southern California is most commonly cited (Southern California Coastal Water Research Project 1974). In the San Pedro Bay area, industrial wastes composed of residuals from oil processing or handling, metallic processes, fish canning, and miscellaneous chemical processes are discharged at the rate of 102 million gallons per day (mgd) (Young et al. 1973). This results in about 10,000 tons of suspended solids per year being added to the bay.

In 1973 the major municipal wastewater dischargers in Southern California released a total of approximately 970 mgd, giving a total suspended solids load of nearly 300,000 short tons per year (McDermott 1974). The total industrial and municipal pipe discharges in the Southern California area was over 1000 mgd but the resulting suspended solids load was less than 0.5 million tons for the year.

Dredge Spoil

Dredge spoil is, by weight, the most significant class of material disposed of in the oceans. In 1968 and 1973, the tonnage of dredge spoil remained approximately five times the tonnage of all other dumped wastes combined (CEQ 1970, EPA 1974b). In 1968, 34 percent of the total amount of dredge spoils were polluted based on measurements of: chlorine, biological oxygen demand (BOD), chemical oxygen demand (COD), volatile solids, oil and grease, phosphorus, nitrogen, iron, silica, color, and odor (CEQ 1970). The total amount of polluted dredge spoil, 13,250,000 tons, was in excess of the total amount, 9,782,700 tons, of all other waste materials discharged from vessels during the same year (CEQ 1970).

Control of polluted dredge spoil disposal is made difficult by the unavailability of adequate records of amounts and locations as well as imprecise specification of which disposal operations are tabulated. If the total amount and the amount of polluted dredge spoil are not known, it will continue to be difficult to derive a fair estimate of the effects of dredging disposal operations. The amounts of dredging and resultant disposal should be clearly tabulated. Such a tabulation would include the type of material, the operator, the amount removed, and the amounts placed in specific areas.

PROPERTIES

Volumes of materials are insufficient as indicators of the dimensions of the ocean disposal problems since the potential for harm to the marine environment can vary greatly depending on the characteristics of the materials. Therefore, the wastes from various industrial, municipal, or other sources must be considered in terms of their major and minor constituents, as well as their interactions both within the waste mixture and with the environment into which they are introduced. Knowledge of the physical and chemical properties of the constituents is basic to determining how the material will move in the environment and what the effects of its introduction might be. Some wastes composed of very high levels of toxic constituents are prohibited. The existing legislation excludes the dumping of radiological, chemical, or biological warfare agents; high level radioactive wastes; and certain levels of organohalogens, mercury, cadmium, and petroleum hydrocarbons. The outright exclusion of these more toxic materials constitutes a significant reduction in environmental risk.

For many of the wastes placed in the ocean, however, toxic materials are a small part of one or more of the constituents. Thus, control of a fraction of the waste material rather than of the total amount must be achieved. Major and minor constituents of wastes from various sources in the New York metropolitan region are shown in Table 2 (Gross 1972). In order to ascertain the immediate physical effects of disposal of these constituents, their density can be compared with that of seawater to determine whether the material will move predominantly on the surface, in the water column or on the bottom. The relationship between the chemical characteristics of the constituent and its effects depends on the spatial location of the material in the marine environment, ambient conditions at that location, and the manner in which the chemicals are bound in the waste.

Physical properties of the waste will influence its transport, dispersal, and settling properties, and can be used, once the characteristics of sites are evaluated, to predict the potential paths of the waste material. The surface moving materials in Table 3 may be classified as those that float as discrete aggregates or particles and those which form slicks. The interior moving materials, those that remain in the water column, may be classified as

TABLE 2

Waste Constituents

Wastes	Sources	Major constituents	Minor constituents	Disposal area
Municipal refuse	Domestic, industrial	Paper and wood (50%)	Glass, stones (10%)	Landfill
		Food wastes (12%)	Metals (8%)	Incineration
Dredge wastes	Harbor and channel construction and maintenance	Sand, shell, gravel	Sewage solids	Ocean
		River sediment	Industrial wastes	
Rubble	Construction and demolition	Stone, concrete, steel		Landfill
				Ocean
Sewage solids	Municipal sewage systems and treatment plants	Organic matter (50%)	Industrial wastes	Ocean
		Alumino-silicates (50%)		Harbor
Coal ash	Coal combustion, primarily power generation	Quartz, mullite		Ocean
Agricultural	Duck farm wastes	Sand		Streams
		Organic matter		Estuaries
Chemicals				
Fermentation	Pharmaceutical industry	Organic matter		Ocean
Acids	Metal processing			Ocean
Alkali	Petrochemical industry			Ocean

Source: Gross (1972)

TABLE 3

Physical Characteristics of Waste Materials, etc.

Mode of Transport	Physical Characteristics	Example
Surface moving	a. Float as discrete aggregate	Floatables
	b. Form slicks	Light fluids
Interior moving	a. Density near that of water	Dissolved, colloidal, or suspended materials
	b. Density varies with respect to water	Settling or rising materials
Near bottom moving	a. Move continuously	Dense liquids, nepheloid layers
	b. Move rarely	Bottom sediments

those that move as fluid particles with a near ambient density and those that settle or rise over the time periods under consideration due to density differences. Bottom moving materials may be classed as those that move more or less continuously and those that move only as a result of strong oceanographic forces. It is assumed that materials of the same density and particle shape, whether waste or natural sediments in origin, will behave in an equivalent manner. Transport of waste material of high settling velocity can be, for instance, equated to that of natural sands or gravels. Transport of slow-settling wastes can be equated with silt and clay transport.

To assess the possible impact of ocean dumping and changes that disposal may bring about, the chemical properties of the materials must be evaluated in addition to the physical properties mentioned above. Disposal may simply alter the concentrations of the constituents normally present or it may introduce materials not naturally present. Control of rates and methods of introduction of chemically mobile materials is a means of protecting the environment.

Trace element excesses can have important impacts on biological systems. For practical purposes, trace elements are those normally present in marine waters in concentrations of less than one milligram/liter. Because they occur in relatively low concentrations in marine environments, increases in the concentrations of trace elements due to ocean dumping of certain materials may be significant. Quite small changes in some trace elements such as mercury, cadmium, and copper have been demonstrated to be harmful to some marine organisms (Tables 1, 4 of Waldichuk 1974). Slight changes in other trace elements may have equally detrimental effects.

For these reasons, chemical evaluation of materials to be dumped should not be restricted to those toxic elements occurring in high enough concentrations to alter environmental levels; all known toxic elements should be chemically evaluated, even those for which there if little evidence about their interactions with or transformation by the marine biosphere.

The spatial and temporal variations in the distribution of phosphate, nitrate, and various fractions of total organic carbon (TOC) need to be considered in deciding on the compatibility of a given dump site and the proposed materials. When too many of these nutrients are dumped, overgrowth of certain organisms may result, with attendant problems of oxygen depletion and water quality deterioration. Deleterious effects will also be reflected by the biota of the water column and by the underlying benthic community. Nutrient and dissolved oxygen concentrations in a given area can serve as an easily measured gross indication of the water quality of that area.

Relatively high nutrient concentrations in a potential dumping area are not of primary concern if the waste to be disposed of is unlikely to trigger objectionable growth. Care must be taken in assessing this likelihood because inhibiting or limiting nutrient phenomena may prevent objectionable growth in the dump area, but it may also trigger such growth somewhere downstream after sufficient dilution has occurred. Ambient levels of nutrients within the dump site are of particular importance when potential disposal material, such as dredge spoil and sewage sludge, contains relatively high levels of available nitrogen, phosphorus, and carbon.

Excretory products, chelating agents, vitamins, hormones, and medicinal wastes containing biologically active materials constitute substances which could determine ecological responses (NAS 1975b). In the current state of our knowledge, it is often difficult to measure their concentrations or to predict their effects.

Synthetic compounds can be extremely detrimental when released to the environment because the biota have not been previously exposed to them and functional detoxification and degradation pathways may not exist (NAS 1975b). The problem is aggravated by the rapid rate at which new synthetics are created and distributed, analytical difficulties presented by such compounds, and the lack of adequate production data and laboratory standards.

Often it is only after significant discharges to and dispersion in the environment have occurred that the presence of new synthetic materials is recognized and monitoring techniques for them are developed. (Garrett 1957, Henderson et al. 1960, NAS 1975b). Criteria for selection of synthetic compounds must therefore be developed and applied in the context of probable contamination at a variety of levels both of waste materials requiring disposal and of marine waste disposal sites.

Petroleum and petroleum products are constituents of municipal and industrial wastes and are commonly found in dredge spoil from harbors. The most practical method of controlling the introduction of petroleum hydrocarbons into the oceans through municipal and industrial wastes and dredge spoil is to prevent the contamination of these materials by petroleum. Petroleum hydrocarbons, and wastes containing significant amounts of them, should not be considered for ocean disposal. Petroleum products may accumulate in organisms consumed by man (Blumer et al. 1970). The additional stress produced by hydrocarbons on organisms may result in direct kills or a variety of sublethal effects (Blumer et al. 1971). In addition, petroleum hydrocarbons are introduced into the oceans through the atmosphere (SCEP 1970, NAS 1975c) and through accidental spills (NAS 1975c).

EFFECTS

Effects of ocean disposal activities reflect both the amounts of waste materials discharged and their characteristics. These effects may be considered through (1) analysis of the effects of individual elements, compounds, or wastes in controlled situations; (2) site-specific analyses in the marine environment where one pollution source may be isolated; and (3) analysis of a geographic area where a variety of inputs may be important. Since the analyses in the last two cases incorporate more of the observed variability of the waste and of the marine environment, the resulting complexity makes it difficult to isolate individual causes. The effects of a given material may be reasonably well defined in absence of multiple possible causes. In addition, the synergistic or antagonistic effects of dumping in a coastal area where rivers and estuaries are already delivering pollutants may be observed. However, the attribution of individual cause when observation is made of the aggregate effect is quite difficult in most cases.

In the first approach, analysis of an individual element, compound, or waste, the effect on growth or production may be envisioned as three zones of dose and response (Perkins 1974:438). The resultant response curve has a zone where growth is limited owing to a deficiency of the material; a zone of tolerance where maximum production may occur; and a zone of "pollution" where there is an excess of the specific material which inhibits growth. The relationship between this specific physiological response and the larger scale ecological implications and responses is important, since analytical techniques generally emphasize the former for simplicity while environmental problems often demand solutions to the latter.

The physiological responses of various organisms to heavy metals, pesticides, polychlorinated biphenols, oil, and dispersants are treated by Vernberg and Vernberg (1974). Limits for a variety of materials potentially harmful to the marine environment have also been estimated elsewhere (NAS 1972b). A National Academy of Sciences (1975b) report considers effects of transuranic elements, synthetic organic chemicals, metallic wastes, and medicinal wastes on the marine environment. The environmental effects of dredge spoil, industrial wastes, sewage sludge, refuse, radioactive wastes, military explosives, and chemical warfare agents are briefly examined by Smith and Brown (1971). Often, acute effects are measured and their relevance to nature and specific wastes established through analysis of waste composition and dilution in the environment. The chronic and synergistic effects are not as frequently specified although they are basic to understanding environmental damage.

Site analysis of the effects of specific dumping or discharge operations, the second approach mentioned above, incorporates waste and environmental variability where one source may be isolated. Thus, impact or effect may be determined without the large degree of extrapolation implicit in physiological response studies. Acid waste and sewage sludge dumping off the mouth of Delaware Bay represents a relatively isolated discharge situation. There, no major buildup of coliforms was detected at the sewage sludge dump site (Lear and Pesch 1975). Animals and/or sediments at either or both the sludge and acid waste sites were found to be enriched in 11 of the 13 metals examined (NOAA 1975b:18-19). The mahogany clam and the scallop showed enrichments. An example of direct impact on human health attributable to a specific discharge operation is the mercury poisoning in Japan. There, as discussed by Perkins (1974:481), the mercury from industrial effluent caused many deaths.

The third and perhaps most realistic manner of assessing ocean disposal impact is to analyze a geographic area subject to a variety of pollution sources or stresses. Coastal areas near major metropolitan regions are subject to various inputs from the atmosphere, rivers and estuaries, and through disposal operation. The New York Bight which, by the end of 1974, received five sixths of all the United States' nondredged waste material (NOAA 1975b), has been subject to physical, chemical, and biological alteration. Physical change in the configuration of the bottom arising from introduction of dredge spoil and other material has been documented by Williams (1975) and NOAA (1975a). In each case, a mound of disposed material has been identified. In the lower part of the water column, the concentration of suspended solids at the spoil and sludge sites is 30 to 50 percent above background, and the grain size distribution in sediments north of the sludge site may be affected by an increase in fine material.

Chemical alteration of areas in the New York Bight has been shown by increases in metals and sediments at dump sites. Gunnerson et al. (NOAA 1975a:Figure 21) show an increase in lead from less than 20 ppm in dry sediment to more than 50 ppm in the area of the spoil and sludge sites. In addition, copper, chromium, lead, zinc, and nickel show similar distributions. Another chemical index of sewage sludge is the ratio of carbohydrate to total organic carbon (normally about 10), which shows values of 50 and above in the Hudson canyon (NOAA 1975a). Nutrient distributions in the water column and at the surface show small alterations associated with disposal operations, while iron concentrations have not changed since 1948 (NOAA 1975a).

Minor biological impact in the bight has been noted in the form of changes in some protozoan distributions (ciliates that feed above the sewage sludge on bacteria) (NOAA 1975a) and species composition changes in benthic invertebrates at the sludge and spoil sites (Steimle and Stone 1973). Fin rot has been found in 22 species of fish in the Bight (Mahoney et al. 1973). Shellfish at or near the spoil sites contain high concentrations of coliform bacteria (Buelow et al. 1968); therefore, in 1970, the Food and Drug Administration closed to shellfishing an area around the dump sites and, in 1974, extended the area landward. Some forms of coliform bacteria in the New York Bight have a resistance to heavy metals and some antibiotics (Koditschek and Guyre 1974) which could cause health problems.

In summary, the amounts, physical properties, chemical properties, and effects of materials placed in the marine environment form a framework for assessing the magnitude of the problem and its changes through time. These effects, whether determined through controlled, site, or geographic analyses, vary in importance. The New York Bight, for instance, an area with many pollutants being delivered to it, shows several signs of resource degradation. Knowledge of amounts of materials, their properties, and effects, together with the basic processes described in the following chapter, will provide an improved scientific and technical basis for management alternatives.

CHAPTER III

PROCESSES AFFECTING THE DISTRIBUTION AND FATE OF MATERIALS

Decisions on management and future research must, as a first essential, consider the processes that affect the distribution and fate of materials. To the extent that the results of these processes are well known in a predictive sense, management systems may incorporate the constraints such knowledge dictates. To the extent that these processes are poorly known, additional research may be necessary. This chapter reviews the physical, geological, chemical, and biological processes which are a basis for examining the management alternatives discussed in Chapter IV.

PHYSICS

The predominant physical oceanographic factors affecting transport of materials near the sea surface, in the water column, and near the sea bed are indicated in Table 4. Surface waves are of primary importance for materials carried in surface waters, and may also be important for bottom transport on the central and inner shelf. Directional wave spectra that are obtained over a period sufficient to resolve statistically seasonal effects at relevant geographic locations are essential for inner shelf erosion and bottom transport computations. In addition, information on wave refraction and scattering in the vicinity of shallow water dump sites and outfalls is necessary for such calculations. Particular attention should be given to longer period storm waves.

Shoaling or breaking internal waves may be important to the erosion or deposition of bottom materials in regions with large gradients in the density field near sloping topography (Southard and Cacchione 1972). This is often the case near the shelf edge and over the central shelf, and a proper examination of the velocity and density time series for these features should be carried out at such sites on a seasonal basis.

Ocean currents generally are important for all three transport modes. However, different velocity field spectrum bands with a frequency of less than one cycle per hour are important for various substances, such as fine clays and silts in suspension at various density discontinuities. Movement of bottom materials is caused by transient currents associated with severe meteorological events such as local storm surges, wind-driven currents, and wind-generated waves. During such events, superposition of these transient

TABLE 4

Principal Mechanisms Affecting Transport and Dispersion

Factors influencing motion Physical Characteristics	Surface Waves	Internal Waves	Tidal and Inertial Currents	Subtidal Currents	Seasonal Current Variability	Bathymetry	Meteorological	Hydrography
SURFACE								
Float as discrete aggregate	x		x	x	x		x	
Form slicks	x		x	x	x		x	
FLUID INTERIOR								
Density near that of water			x	x	x	x	x	x
Density varies with respect to water			x				x	x
NEAR BOTTOM								
Move continuously	x	x	x	x		x	x	
Move rarely	x	x	x	x	x	x	x	

currents with the local tide-driven currents further enhances the rate of bottom transport because of the inherent nonlinearity of the sediment transport process.

Substantial shear can occur in basic flow and lead to concentrated or diffuse turbulent mixing. Reverse flows near the seabed can develop under a wide variety of conditions. Recent experience in continental shelf physical oceanography clearly indicates that both the density and velocity fields must be properly resolved if an accurate picture of the oceanographic situation is to be obtained. Therefore, procurement of suitable field data on low frequency current and density is the core of any physical oceanography study aimed at ocean disposal problems. In addition, estimates of momentum and mass-mixing coefficients are required.

For materials transported at the sea surface, local wind stress and local current and wave information are required for predicting surface material redistribution.

GEOLOGY

The continental margins of the United States are varied, in terms both of physiography and physical processes (Heezen et al. 1959, Byrne 1963, Emery 1969, Emery and Uchupi 1972). The most commonly recognized geomorphic units are the beach and nearshore zone, outer continental shelf, submarine canyons, continental slope and rise, deep sea trenches, and abyssal hills and plains.

In shallow nearshore waters where surface waves reach to and affect the bottom, coarse materials (those with a high settling velocity) normally move onshore (Inman 1949, Swift 1974), although occasionally, under certain wave conditions, movement alongshore and offshore may occur (Cook and Gorsline 1972). In this area, fine-grain materials of low settling velocity are inhibited by wave motion from reaching the bottom and are normally carried offshore. Although the high wave turbulence makes the nearshore zone an area of efficient dispersal, the tendency to transport coarse materials onshore to the beach makes the zone undesirable as a disposal site for pollutants. However, the introduction of unpolluted dredge spoil of appropriate grain size could be beneficial in restoring material to eroded beaches.

The continental shelf is often the most convenient location for ocean disposal in terms of transportation costs. In outer shelf and upper slope waters, unidirectional currents generally predominate near the bottom. These tend to flow roughly parallel to the continental shelf edge with a common offshore component in the southern New England area (Beardsley and Butman 1974). Tidal currents at the shelf edge can be very strong (Stewart and Jordan 1964). From simple continuity considerations at a given shelf site, the balance in the sediment input versus sediment loss will be reflected in erosion or deposition related to these currents (Ludwick 1974). We commonly define this balance between input and loss without knowing those quantities individually, and can use it to provide an indication of the fate of wastes being disposed of at the site. If, for example, the site favors a net erosion of fine material, then the waste would be dispersed unless the discharge rate is high enough to shift the balance toward deposition by overwhelming the available transport energy. A major flood on an intermediate energy shelf off southern California resulted in such a shift to deposition (Drake et al. 1972).

Continental slope and rise disposal is susceptible to widespread dispersal as a result of catastropic downslope mass movement (Heezen and Menard 1963) or of continuous unidirectional currents (Heezen and Ruddiman 1966, Field and Pilkey 1971). Deep bottom currents are primarily a problem for fine materials (silts and clay-sized materials). Burial of waste materials by natural processes is unlikely to any extent in most regions, with the exception of the Mississippi Delta where rapid accumulation occurs.

Submarine canyons have also been considered as potential disposal sites. Some of the California borderland canyons, for instance, empty directly into small, relatively deep nearby basins. Waste material moving across the shelf would tend to settle preferentially in the depression until reaching the bottom, where there is evidence of considerable hydraulic activity in both up and down canyon directions (Shepard and Marshall 1969, 1973). Heavier material placed at the canyon head may work its way down canyon and, at times, be flushed into the deep ocean by turbidity currents (Felix and Gorsline 1971, Drake and Gorsline 1973). There is also evidence of more dense water moving up canyon and possibly moving suspended material back up toward shore. Canyons also apparently provide important migration routes for some biological species. Thus, we should be cautious about considering canyons as possible waste disposal sites.

The current patterns and variability of deep ocean trenches are largely unknown. The distribution of water characteristics suggests that the turbulent mixing and spreading of denser materials in trenches are probably extremely slow. Burial of the waste material by sediments may occur where subduction is occuring in trenches. More important, however, is the high seismicity, which can generate slides, slumps, faulting, and deformation of substrate. Under these conditions, liquefaction or other processes may mobilize wastes. Therefore, trenches associated with subduction zones are not good dump sites because of the large uncertainties about the effects of use.

SEA TO AIR TRANSFER

Although experiments have yet to be done at a disposal site, there is sufficient evidence to suggest that the material in the surface slick, or within about a micrometer of the surface, is ejected into the atmosphere on jet drops from bursting bubbles. Since the surfaces of both fresh and salt waters, especially where slicks are prevalent, often contain concentrations of bacteria higher than those in the water beneath (Parker and Barson 1970, Sieburth 1971, Hatcher and Parker 1974), these surface bacterial concentrations should be reflected in the drops ejected from the bubbles. This was found to be so in laboratory experiments both with fresh water (Blanchard and Syzdek 1970, 1974) and with seawater bacteria (Bezdek and Carlucci 1972, Carlucci and Bezdek 1972). Bacterial concentration factors were in the range of 10 to 100. In seawater, they were considerably higher for the natural bacterial population than for a pure culture of Serratia marinoruba.

Perhaps even more important than the bacterial concentration at the surface of the sea is the concentration that undoubtedly increases with time on bubble surfaces. We have strong reason to suspect that bubbles rising through the high bacterial concentrations of the waters at a sewage disposal site will scavenge and carry many bacteria to the surface of the sea. Although the scavenging efficiency appears to be far less than 1 percent (Carlucci and Bezdek 1972, Blanchard and Syzdek 1974), the bursting bubble produces very efficient water-to-air transfer (Blanchard and Syzdek 1974).

The above considerations are far from academic, for it is known that sewage treatment plants, cooling towers, and tanneries, for example, produce bacterial aerosols that travel into outlying communities (Spendlove 1974) and have produced viral disease (Wellock 1960). Many of these aerosol particles produced by bubbling and splashing of liquids are in the size range (1 to 5 microns) where maximal alveolar penetration occurs (Hatch and Gross 1964).

Not only can bubble mechanisms concentrate and eject bacteria-laden droplets into the atmosphere, but they no doubt operate in a similar manner for particulate trace metals in the sea. Particulate trace metals such as lead, iron, manganese, chromium, and vanadium (Duce et al. 1972, Piotrowicz et al. 1972) have all been found in significantly higher concentrations in the surface microlayer.

The bubble mechanism has also been implicated in the water-to-air transfer of organic material, presumably the surface active component. Enrichments of organic carbon on the sea-salt aerosol have been found to range from several hundred to several thousand (Hoffman and Duce 1974).

CHEMISTRY

Many chemical processes can take place at or near the points of waste introduction into the marine environment (nearfield). These processes can change the physical state of the material from solid to liquid and vice versa but rarely to the gaseous state. Formation of complexes with chelating agents can prevent precipitation of ions that would otherwise be insoluble in seawater.

Most oxygen in the ocean enters from the atmosphere through the air-water interface. The rate of this exchange is fairly slow and depends on surface mixing rates and boundary layer diffusion. The concentration of oxygen at saturation is a function of both salinity and temperature of the water and, therefore, varies on a seasonal basis. Waste disposal may cause an initial transient decrease in oxygen due to microbial actions and inorganic oxidation of reduced compounds (Odum 1960). Oxygenated seawater will oxidize such materials as ferrous and manganous ions, causing them to precipitate. There will then be a longer term oxygen demand as disposal materials slowly degrade.

The total level of dissolved oxygen in sea water is determined by the aggregate effect of depletion and renewal. This level is a major factor in the survival of many organisms.

The presence of hydrogen sulfide, a product of anaerobic reduction of sulfur compounds. indicates conditions which may profoundly affect biological communities. Hydrogen sulfide is toxic in low concentrations to many aerobic organisms. The presence of hydrogen sulfide indicates that the system is anoxic and that a sulfide tolerant community may be present. When hydrogen sulfide is released into oxygenated water, it is oxidized within hours and may account for a major fraction of the initial chemical oxygen demand of certain wastes. Because of its short half-life in aerated water columns, hydrogen sulfide does not normally represent the long-term hazard that certain trace metals and chlorohydrocarbons may.

Bubbles and other active surfaces, such as inorganic particles, can concentrate soluble organic material. Such material can serve as food for certain marine organisms. The ecological role of this process is not well known, but it could be a mechanism for the active transport of nutrients.

Naturally produced and artificially introduced organic compounds in seawater can form chelates and other complexes with metal ions. One result may be to make the metal soluble, which, as a consequence, may also alter the physiological effects of the metals. Thus, the presence of naturally produced ligands may serve to detoxify certain metals, such as copper, or render others, such as mercury, more toxic.

Biochemical processes can alter waste materials in the ocean. Photosynthesis is accompanied by increased oxygen and decreased carbon dioxide tensions and a decrease in pH. Its rate varies with light, nutrient concentration, and therefore, to some extent, with temperature, depth, and other factors. The changes in pH may alter the solubility of carbonates so as to result in their solution or precipitation. Photosynthesis within sulfur bacteria can take place when anoxic, sulfide-bearing environments occur within the photic zone. Hydrogen sulfide, instead of carbon dioxide, is consumed and free sulfur is produced.

Respiration may be thought of as the reverse of photosynthesis, with oxygen being consumed and carbon dioxide released. As the dissolved oxygen values reach near zero, nitrate reduction producing nitrite, and denitrification producing free nitrogen will follow. Nitrate reduction and denitrification are followed by sulfate reduction, as more organic matter is oxidized. This process introduces sulfides into the water, and is also accompanied by the production of inorganic compounds of phosphorus, nitrogen (specifically ammonia), and carbon dioxide. When mixed with oxygenated water, the sulfides will be oxidized to such compounds as sulfite, thiosulfate, sulfate, and free sulfur.

Other specific biochemical processes which need to be considered are the bacterial methylation of mercury and arsenic, the anaerobic production of methane, and the possible reduction of phosphate to compounds that are flammable.

Redox potential profiles within the sediments may be useful for at least two reasons. First, they generally specify the conditions of the site with regard to oxidation-reduction reactions presently occurring. Second, they give important predictive bases for the transformation and release of heavy metals from contaminated wastes.

BIOLOGY

The biological processes in a potential disposal site area must be known well enough to characterize their species composition, population dynamics, and temporal variations, and the migratory patterns of the resident species. Organisms most likely to be affected by the proposed wastes, and the most likely pathways for biological accumulation and transport of waste-derived materials must be identified. Particular attention should be given to those food webs or pathways that could lead to humans. Commercial assets, species on which several others depend, rare or endangered species, breeding and nursery grounds, migratory patterns of species that traverse potential disposal sites, and unique habitats need special recognition in the evaluative process. The community condition, whether relatively undisturbed or extensively stressed, may also be a relevant. Quantitative and qualitative assessment of community structure through analysis of species diversity and the health of the organisms present helps in making this estimate.

Bioassay is a fundamental technique used to relate biological processes to the stresses induced by various pollutants. Bioassay procedures need to be carefully defined in order to relate them appropriately to waste and site characteristics and to document disruption of basic biological processes. The term bioassay should be defined in the broadest sense. "Bioassay test" should apply to any tests that demonstrate biological response. Acute bioassays are, traditionally, bioassays that demonstrate the level of toxicant that kills a specified percentage of the experimental population within a defined exposure time. This test at best measures short-term effects resulting in death. Chronic effects that develop over time should be the focus of marine bioassay studies. Subtle deleterious effects on biological systems and man should also be evaluated.

Ocean disposal activities create long-term exposures to potential toxicants, especially for benthic systems. To determine the biological effects of such exposures, chronic bioassays should be used. These can be defined as tests that demonstrate the biological effects of extended exposures to toxicant levels that are considerably below acute doses. They should be performed both in the laboratory and in situ. Field bioassays may be carried out on natural populations or caged experimental organisms in the area of the dump or dump site. Such response parameters as growth, behavior, reproduction, recruitment, gametogenesis, larval development, productivity, and histopathology should be used as monitors of chronic damage. For certain organisms, especially for those with a short life history, mutagenic effects should also be considered. Measures of community function (bioaccumulation via transport mechanisms and metabolic studies) should be considered in chronic in situ bioassays. Concentrations of toxicants present in the exposed organisms should be correlated with any adverse biological effects.

Appropriate bioassay organisms should be abundant, ecologically significant, and native to the site or region where the dumping will occur or has occurred. Commercially important species should be included. Techniques for handling and evaluating these organisms under test conditions should be developed. A sensitive stage in the life history of an organism should be included in the tests. Bioassay conditions should, to the extent possible, simulate "worst-case" conditions likely to be encountered at the disposal site (i.e., high temperature, low dissolved oxygen, calm seas, and so on).

In conclusion, management plans must be based on an examination of basic ocean processes. Specifically, understanding of these processes is the basis for site selection and monitoring if minimal impact is to be achieved.

CHAPTER IV

SCIENTIFIC AND TECHNICAL BASES FOR MANAGEMENT ALTERNATIVES

MANAGEMENT OBJECTIVES

Existing congressional legislation prohibits ocean disposal of some materials, places restrictions on others, and regulates permit programs for all ocean disposal. The object of this legislation is to:

> "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (PL 92-500 sec.101(a))

and to:

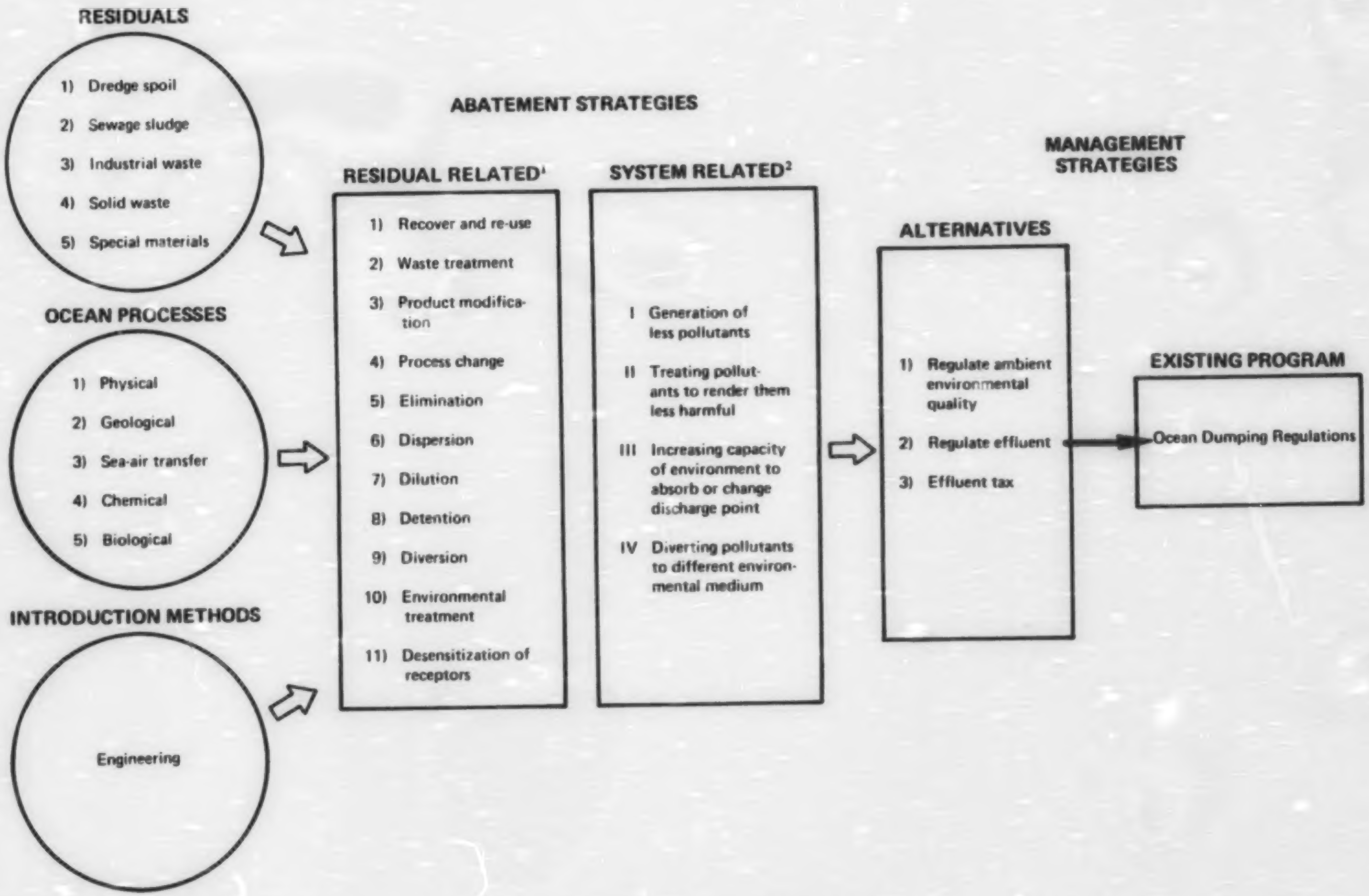
> "regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems or economic potentialities" (PL 92-532 sec. 2b).

This chapter will examine pollution abatement and management strategies (see Figure 3) designed to achieve these objectives. The management alternatives examined will assume that a decision has been made to place waste in the ocean, and that the method of disposal least damaging to the environment will be sought. The analysis will be strictly in terms of the scientific and technical factors on which these strategies must be based: the amount of waste materials, their properties, and the processes that affect their distribution and fate in the marine environment. The constraints that these properties and processes impose on management alternatives dictate that any such scheme must incorporate a comprehensive understanding of nearshore oceanography, of the properties of the waste materials, and of available techniques for handling them. (Any management scheme should also incorporate economic and social considerations; analysis of these factors, however, falls outside the scope of this study.)

Methods for achieving the objectives of the legislation are reflected in the laws themselves, which prohibit and restrict certain materials and establish a means of accepting others. In addition, these methods are delineated by the headquarters of the Agency as it formulates regulations (see Chapter I) and by the regions as they allow or deny specific permits. Thus, evaluation of the ocean disposal program with respect to Congressional intent must incorporate the realization that individual disposal actions are the result of multiple decisions.

FIGURE 3

Management Framework


RESIDUALS
1) Dredge spoil
2) Sewage sludge
3) Industrial waste
4) Solid waste
5) Special materials
OCEAN PROCESSES
1) Physical
2) Geological
3) Sea-air transfer
4) Chemical
5) Biological
INTRODUCTION METHODS
Engineering
ABATEMENT STRATEGIES
RESIDUAL RELATED¹
1) Recover and re-use
2) Waste treatment
3) Product modification
4) Process change
5) Elimination
6) Dispersion
7) Dilution
8) Detention
9) Diversion
10) Environmental treatment
11) Desensitization of receptors
SYSTEM RELATED²
I Generation of less pollutants
II Treating pollutants to render them less harmful
III Increasing capacity of environment to absorb or change discharge point
IV Diverting pollutants to different environmental medium
MANAGEMENT STRATEGIES
ALTERNATIVES
1) Regulate ambient environmental quality
2) Regulate effluent
3) Effluent tax
EXISTING PROGRAM
Ocean Dumping Regulations

Source: 1 NAS (1966); 2 Kneese and Schultze (1975)

This chapter examines several approaches to handling wastes to illustrate some of the basic decisions that are built into the present system. The applicability of particular waste-related abatement strategies to this ocean disposal problem may be determined by correlating the total number of these strategies (Figure 3) with the limits imposed by physical, chemical, and biological processes operating in the marine environment (Chapter III). The engineering methods discussed in this chapter further limit the options by indicating the number of different dispersion or containment modes that are possible. It is important to recognize that any disposal operation has dispersal-containment considerations although they may not be explicity treated. A final assessment must also include scientific uncertainties and associated risks, and the constraints of the legislation. Thus, this chapter will isolate from all abatement strategies those courses of action applicable to ocean disposal operations. Subsequent chapters will examine site selection and site monitoring which are important parts of the adopted abatement strategy.

OCEAN WASTE DISPOSAL METHODS

Physical properties of the waste materials and the environment limit the flexibility of disposal methods. Engineering design cannot alter the fact that the densities of dredged waste, solid waste, and containers of materials result in the disposal point being the site where much, if not all, of the disposed material comes to rest on the bottom of the ocean. Thus, the fate of material that is considerably denser than seawater is determined primarily by ocean bottom processes.

Liquid wastes have densities near that of seawater and may, therefore, be dispersed in the water column through a variety of means. Diffusion models allow choosing, adjusting, and testing the disposal design against desired results. Numerical and hydraulic models have been successfully used in the design of sewage treatment plant outfalls (Brooks 1960, Rawn et al. 1960, Frankel and Cumming 1965, Singamsetti 1966, Fan and Brooks 1967, Hayashi 1971). Numerical models exist to predict movements of wastes discharged from barges (Ahmadi and Goldschmidt 1968, Koh and Fan 1969, Koh and Chang 1974) but these models require further validation and testing. Models of the initial spreading and degradation of oil released on the surface are being developed (Blokker 1966, Cochran and Scott 1971, Ichiye 1972, Waldman et al. 1973). Existing models consider many of the physical properties and dynamic effects of waste disposal but do not yet incorporate chemical or biological interactions which may play a significant role in the environment. Models of the atmospheric dispersal of effluent near the discharge point (nearfield effects) are well advanced, but they have not been applied to design of the discharge as a means of determining the amount of waste introduction to the ocean from atmospheric discharges (O'Viatt 1968). Such modeling would be pertinent at certain coastal locations or in cases of atmospheric emission from shipboard incineration.

In assessing the expected results at ocean disposal sites, it is important to recognize that there may be two effects: (1) an acute effect at the discharge sites lasting for the duration of the dump and for a short time thereafter, and (2) a chronic effect which may last for a long time after the cessation of discharge in the area. The acute effects can be greatly reduced by the proper choice of engineering design for the release method. Chronic effects, however, are not generally controllable by engineering considerations. Disposal sites must be selected with a view to minimizing both acute and chronic effects.

For engineering design, the concept of a mixing zone is important. It must be recognized, however, that the size of the mixing zone depends on the local oceanographic conditions and the release method and rate. Furthermore, the fluid portion of the waste and the various particulate phases may have different mixing zones and dilution media; this should be taken into consideration when formulating guidelines and criteria.

WASTE-RELATED ABATEMENT STRATEGIES APPLICABLE TO OCEAN DISPOSAL

A previous study has considered abatement techniques for all pollutants in all media (NAS 1966). The results, a list of 11 physical methods for pollution control, appear in Figure 3; the system-related abatement strategies are also shown (Kneese and Schultze 1975). Any waste management scheme should examine opportunities presented both by the physical methods for waste handling and by the system opportunities that may, for example, result in the generation of less wastes. Consideration of the latter, however, implies evaluation of economic data as well as broad social questions. Such material, as indicated above, is not a part of the data base addressed here since this report is concerned specifically with waste-related strategies as determined by the attributes of the marine environment and the processes active there.

Within abatement techniques, two general categories are noted. First, there are processes which may be introduced before disposal which will greatly affect the behavior of wastes in the ocean, including: recovery and re-use of portions of the waste, waste treatment, and product modification or process change to eliminate constituents of the waste. Second, there are processes which may occur during or after the disposal operation. This second group includes: dispersion patterns, dilution rates, detention, and diversion. The last two processes use the physical and chemical characteristics of the disposal site to confine the area affected by the waste. Dispersal may occur through the atmosphere, through the water column, or along the ocean bottom. Thus, for liquid waste, ocean disposal implies disposal in the water itself, which results in a high degree of mobility for the waste. Dense solid wastes may be contained on the bottom in isolated areas, or buried after deposition using clean material. Physical processes, waste characteristics, and introduction methods can be exploited to disperse those materials that can be assimilated without harm into the water column.

Disposal methods control the degree of initial dilution that may be achieved for liquid wastes either through diffusion at the disposal site discharge or by dilution prior to introduction. Changes in these initial concentrations may not alter the final fate and effect of a pollutant that is reconcentrated through physical or biological processes. Pollutants which can degrade in the environment, however, may be altered through an initial dilution that permits assimilation to occur with minimal disruption.

SCIENTIFIC UNCERTAINTIES

If the marine environment could be adequately described and the disposal capacity of given environments quantified, the necessary factors would be defined that either prohibit disposal or limit the design criteria for a disposal system. Once the assimilative capacity of a site and the limits on the rate of input of wastes are known, limiting conditions on waste composition, waste treatment, and waste dispersion or containment can be derived and a variety of designs to meet those conditions can be proposed. The necessary information for this is not now available, nor is it likely to be available in the near future. Therefore, a decision method which recognizes inherent scientific uncertainties must be adopted. One such method is the decision case approach. The assumed adequacy of available information represents an important characteristic of the decision-making process. In the ideal case, decisions are based upon complete documentation of environmental information. Other decisions are increasingly influenced by a recognition of the inadequacies of available information. Thus, the bases for decisions range from definite knowledge to virtual conjecture about likely consequences (Bella and Overton, 1972).

For ocean waste disposal, definite information on which to base decisions is sparse. Hence, any decision to use the ocean for waste disposal involves some risk which may be unacceptable to some sectors of society.

CRITERIA AND MONITORING: THE ADOPTED STRATEGY

All the waste properties, ocean processes, disposal methods, and abatement strategies discussed above may be incorporated in several management strategies. Three are mentioned here (Figure 3). First, the management system may attempt to regulate ambient environmental quality as did the pre-1972 legislation. Second, effluents may be regulated as they are by existing legislation, with some additional use of the first approach in the form of monitoring. Third, an effluent tax or other economic sanction may be used to attach some value to the ocean as a waste repository.

The need to select limits for various substances in effluents or in the environment obliges decisions to be made in the absence of adequate information. It is easier to determine whether such limits are exceeded than it is to predict the impact of high levels of the potentially harmful substances in the environment. Thus, environmental or effluent criteria in ocean disposal act as an intermediary between the necessities of discharging waste and of maintaining environmental quality. When such criteria cause social or economic disruptions, they are vigorously challenged. They must therefore be based on the firmest available scientific information, the relative reliability of which is made explicit in a clear and open decision process.

Environmental managers cannot be certain that criteria developed from an inadequate information base will be effective in protecting the environment, especially against unknown chronic effects. For this reason, most management strategies based on criteria are augmented by large monitoring efforts. These are designed to check the adequacy of the criteria by documenting adverse effects which occur even when criteria are met. The monitoring data are then used to re-evaluate criteria and management strategies.

Strategies of this sort involve two important assumptions about the environment. First, they assume that environmental damages are reversible so that when new revised criteria are applied, the conditions in the disposal area will return to their state before damage occurred. Second, environmental damage is assumed to be relatively limited so that catastrophic events which can include losses of human life are not in question. In this regard, the tragic story of the Minamata disaster in Japan (mercury poisoning through human consumption of shellfish) contains an important lesson. In this instance, waste disposal practices were changed only after loss in life and at great cost to all those involved. In the case of ocean disposal, we cannot be assured that environmental damages will be either reversible or limited in scope. Thus, vigilance by government agencies and by the public is necessary.

Under a management strategy involving "criteria coupled with monitoring", scientific activity will consist largely of descriptive monitoring. As a result, basic processes and related causes and effects will be under-emphasized owing to the press of short-term demands.

A management strategy should be established which recognizes the necessary acceptance of initially inadequate information (Bella and Overton 1972). At the same time, the strategy should work to develop the necessary knowledge. Such a strategy should have the following characteristics in relation to ocean disposal of wastes:

1. Disposal operations should be confined to the smallest possible area.
2. Wastes whose chemical characteristics are foreign to the evolutionary history of marine organisms and populations should not be disposed of until these wastes' characteristics have been determined and their effects on the environment ascertained.
3. An irreversible dependence of society on ocean disposal of wastes should be avoided.
4. Wastes that may concentrate as they pass through marine food webs should not be disposed of at sea.
5. Waste disposal should not exceed the capacity of the site to assimilate or retain the wastes.
6. The management strategy should be continually re-evaluated to consider its effectiveness.
7. Steps should be taken to develop the knowledge necessary for the desired levels of confidence in management decisions.

Ideally, the above should be part of present management strategies.

CHAPTER V

SITE SELECTION

This chapter considers one of the management responsibilities, site selection, that the Environmental Protection Agency is beginning to exercise. Since the Agency has inherited jurisdiction over the sites now regulated, it has not been responsible for the selection of most sites. EPA has phased out the use of less suitable sites to create a more manageable system. Criteria promulgated by the Agency on May 16, 1973 (Federal Register 38:12875-6) show approximately 19 sites whose primary uses were for municipal and industrial waste disposal. By June of 1975, only 11 of these sites were in active use (EPA 1975). Tabulation of dredged material disposal sites and amounts is not readily available and, therefore, assessment of restriction if any in that area is not yet feasible. The replacement of historical sites by new sites chosen for their special characteristics will be slow, since extensive survey work must be completed.

The process of selecting appropriate sites for ocean disposal is complex. While there may be a few instances in which marine disposal site selection criteria may be simplified or abbreviated and only a few parameters considered, more commonly a variety of physical, geological, chemical, biological, and atmospheric factors must be considered for each proposed site.

BASIC PRINCIPLES

Chemical changes resulting from ocean disposal are primary considerations in establishing criteria for disposal site selection and monitoring. These changes directly govern the effects of waste materials on biota. It is difficult or impossible to establish acceptable, simple, single-number criteria for chemical elements or compounds without knowing in detail the interactions of these chemicals with biological systems. Thus, the development of verified models is desirable. A modeling approach could permit prediction of the chemical changes and biological effects brought about by ocean disposal. As a first principle, it should be recognized that the ultimate question is the transient, steady state and long-term chemical changes brought about on the site and its surroundings, and the biological effects of these changes.

Characterization of proposed dump sites should include geological descriptions of bottom morphology, the nature of the substrate and the rates of sedimentation or erosion, geotechnical characteristics and seismicity. Physical descriptions of the processes and factors operative at the air-water interface, in the water column and at the water-substrate interface are also necessary.

The waste to be considered for disposal must be accurately described and must be acceptable for ocean disposal under existing regulations. It is difficult to generalize the relative importance of the various components in a typical waste and to predict their cumulative effect on the various ecosystems because, to determine the propriety of a given location, a specific chemical description must be evaluated in relation to specific oceanographic conditions. Only in this way can the best results be achieved. A decision to disperse or to contain the waste can only be made on the basis of the specific chemistry and geography. If potential sites are available, then designs can be made which consider the location and method of discharge and its projected effects.

IMPACT PREDICTION

Predictive analyses of dispersion and biological effects should be used for site selection. Calculation of the most probable concentration fields within, and the transport of materials out of the general region of specified sites or outfalls, under a variety of appropriate meteorological and oceanographic conditions, is an important part of any analysis. A sound computation method for the transport of materials is an ancillary part of the prediction question. The primary basis of prediction should be what is observationally known about the area. For satisfactory results one must rely at least in part upon extensive field measurement programs to produce the necessary physical oceanographic information.

Arguably, each physical variable is important in every oceanographic problem. Detailed and precise calculation, however, will probably neither be necessary nor possible in the foreseeable future and we should therefore concentrate upon the oceanographic phenomena of greatest importance in each transport problem, listing where possible other potentially important parameters. This can be done for surface-moving materials in a series of semi-empirical models which estimate the trajectories given data on local winds, waves, and currents (Hoult 1972). The usefulness of these models for long-term prediction depends on the accuracy of form drag and windage characterizations of the surface materials and knowledge of the local wind and wave conditions. In addition, a high level of understanding of regional surface winds as a primary forcing function can simplify the modeling problem. While a definitive statement must await the proper assessment of existing models, it seems feasible that a semi-empirical dispersion model can be constructed to give useful long-term probabilistic trajectory and dispersion estimates for average and extreme conditions.

The numerical models currently used to predict surface waves are essentially refinements of earlier operational models developed by the U.S. Navy which have proved valuable to shipping. New computer models, however, allow a much more detailed incorporation of the latest experimental and theoretical advances in the study of wave generation. Furthermore, orbiting satellites and sky wave radar may soon be able to provide a good synoptic picture of the surface sea state all over the globe. With accurate weather forecasts, computer models would be able to predict future sea states. Indeed, it may turn out that the ultimate limitation to wave forecasting will be the accuracy of the weather forecast rather than the wave-prediction model itself.

Materials which move within the water column provide a much more difficult and more important prediction problem. Unfortunately, the physical mechanisms controlling turbulent mixing of mass and momentum within the water column are so complicated and poorly understood at present that the dispersion of a completely passive or neutrally buoyant tracer in the water column cannot be accurately characterized in terms of mean or average physical variables. Thus, the fate of those discharged materials with neutral buoyancy cannot as yet be accurately predicted.

Some hydrodynamic models have been constructed which give reasonably accurate predictions of tidal and near-tidal frequency currents in enclosed basin-like lakes and semi-enclosed basins like rivers, estuaries, and small bays (Platzman 1963, Rao and Murty 1970, Simons 1971, 1972, 1973a,b, Birchfield 1972, 1973, Csanady 1973, Bennett 1974). These models cannot be straightforwardly applied to an open shelf because the coupling of any shelf area with the rest of the shelf and with the deeper ocean is not understood sufficiently to provide the necessary boundary conditions for deterministic models. The physical basis for the chosen boundary conditions used in the existing EPA two-layer mesoscale circulation model for the New York Bight (Laevastu and Callaway 1974) is unclear. Therefore, the accuracy of its long-term advective and dispersive predictions is in doubt. While the descriptive physical oceanographic data on the mid-shelf and slope regions are too limited in many geographic areas to allow adequate model verification, studies of open ocean tides are beginning to provide insight into the boundary conditions that could be used for modeling a coastal subregion.

Model predictions of mean water movement caused by tidal currents have been made with some success in semi-enclosed basins where tides are relatively strong and the boundary conditions accurately defined. In the mid-continental shelf and slope regions, dispersion by tidal currents is probably subordinate to the advection of materials by the mean and the energetic subtidal transients caused by strong meteorological and deep oceanic forcing. While increased sediment transport due to intense storm-generated currents has been well recognized, the intermittency and variability of shelf currents are just being documented. Hydrodynamic models developed for the prediction of non-tidal storm-generated surges may be useful in "worst case" estimation of the mesoscale currents and advective transport of passive tracers in a simple unstratified situation (Hansen 1956, Welander 1961, Platzman 1963, Jelesnianski 1965, 1966, 1967, 1970, Jelesnianski and Taylor 1973). Recent work by Forristal (1974) suggests that realistic prediction can be made with this class of models. More field verification of these models is needed, however, before their accuracy and usefulness to ocean dumping can b[illegible]ssessed in detail.

Over the past decade, fully three-dimensional numerical models for calculating ocean circulation have been developed by NOAA and the meteorological services of many countries. Using methods initially developed for numerical weather forecasting, these models predict the response of currents at deeper levels given the surface flux of heat, mass, and momentum. While several multi-level models are being used to study mesoscale variability in the open ocean, these models have not yet been applied to coastal circulation problems. The success of this fully three-dimensional numerical approach will depend on the specification of proper boundary conditions.

Near-bottom and bottom materials are the final materials to consider in this discussion of predictive analysis for site selection. Estimates of transport near the sea-bed can be made with tolerable success when (1) sufficient information on bottom currents is available either from a physical oceanographic model or from a comprehensive measurement program and (2) the bottom topography is accurately known. Fortunately, it is somewhat easier to estimate the spatial structure of near-bottom than of interior currents from the input data, and the former are much less sensitive to density stratification. At present, use of bottom current meter arrays is the most attractive and perhaps the only feasible approach for determination of the bottom current field. For nepheloid transport, the concentration profile can be used to help determine fluxes. In the case of well characterized clastic sediments, crude methods of determining concentration fields are available (Smith and Hopkins 1972, Sternberg and Larsen 1975). Unfortunately, concentrations cannot be calculated to better than an order of magnitude owing to the difficulty of determining the upward particle flux at the sea-bed.

While the physical fate of these materials can be predicted with a reasonable degree of theoretical and empirical support, the basis of the prediction of their biological effects is less reliable. Therefore, prediction is attempted by qualitative analogy with previous discharges and their impacts (Hartman 1960, Clendenning and North 1960, Reish 1960). Bioassay, defined here as any test that demonstrates a biological response, is another method of attempting to predict the effects of waste discharge. Its importance and general use are described in Chapter III.

THE DEEP OCEAN

Data for the evaluation of the deep sea as a disposal site are inadequate. This is due to: difficulties in conducting bioassays; slow rates of mixing and diffusion potentially resulting in anaerobic conditions; slow organic degradation; and narrow tolerance ranges for sensitive assemblages of organisms. Although the area is relatively stable in comparison to the shelf and nearshore, the much greater scientific uncertainty, and consequently increased risk associated with off-shelf disposal, dictate that any but the most innocuous use of the area should be approached with extreme caution.

SITE CAPACITY

Each disposal site has a unique capacity with respect to material type and method of disposal. Capacity can be a fixed ultimate volume or can be an open-ended renewable capacity. Containment sites will generally, but not always, have fixed capacity limits while dispersal sites will have a capacity expressed as a rate of introduction of waste. Capacity depends upon a number of interrelated factors, the most important of which are: the nature of the waste material; the quantity, frequency and rate of disposal; physical, chemical, and biological characteristics of the environment; and the physical dimensions of the site. These data should be used to develop volume estimates of the capacity for containment disposal and rate of introduction estimates for dispersive disposal.

In a containment site, important geological consequences which determine the ultimate capacity are shoaling, the alteration of wave patterns and overloading of the substrate. In a dispersal site, the capacity will depend upon the balance between the rate of introduction and the rate of removal or degradation.

SITE ABANDONMENT

Site abandonment can become necessary for several reasons. One may be overloading of a site resulting either from errors in management or from unavoidable physical limitations imposed by a site on contained wastes. Another may be differences in the disposal method brought about by legislative changes or advances in waste production and control. Finally, abandonment may be the result of changes in the value of the site due to changes in adjacent coastal zone use. A site located off relatively low-density population areas of the adjacent coast may become an important recreational area if the neighboring coastal population markedly increases. This may change the decision-making constraints originally determined at the time of site selection.

SUMMARY

While a series of detailed scientific analyses would be an ideal basis for site selection, decisions can rest on a few fundamental principles which allow impact predictions to be made. A description of the chemical composition of the waste is a basis for determining the transient, steady state, and long-term chemical changes in the site and its surroundings. This determination of the fate of the material and the extent to which it is contained or dispersed rests on the geological and physical oceanographic characteristics of the site. The predictive analysis of dispersion is obtained through verified models of surface, water column, and near-bottom transport of components of the waste. Bottom transport of solids may be considered through analysis of geologic transport processes.

Minimization of potential biological impact, one main objective of site selection, is obtained through analysis of the above and of their impacts on the biota. These impacts may be estimated by qualitative analogy with other disposal situations (Chapter II, Effects in New York Bight, for example) or through bioassay procedures.

An important, although often ignored, consideration for site selection is the assessment of capacity for a specific area, since this is a key determinant of the appropriateness of abandonment. Material type and method of introduction will determine capacity. A maximum capacity will need to be fixed for materials with high densities and negligible rates of degradation. Often on-site or near-site containment will result from the disposal of such materials. For materials that degrade on a time scale similar to that of physical oceanographic processes, dispersive disposal is often appropriate, and a renewable capacity, or capacity dependent on rate of introduction results. A site may have to be abandoned because of mismanagement leading to overloading; because of changes in legislation or in the waste itself; or because of changes in the value of the disposal area. Thus, the selection parameters for any site must incorporate the possibility of future abandonment.

CHAPTER VI

SITE MONITORING

The considerable uncertainty associated with the effects of ocean disposal operations, and the consequent lack of thorough predictive models, necessitates monitoring for most materials. The general concepts and strategies of ocean monitoring have been described in several studies (SCEP 1970, NAS 1970, 1972a, NSF 1972, 1974, NOAA 1972, EPA 1974a). Specific problem areas have been considered in detail, such as radioactivity (NAS 1971) and petroleum (NAS 1975c).

This discussion of monitoring concentrates on those geographic areas selected as disposal sites. The degradation of these relatively restricted areas is, however, a far less serious threat than the chronic pollution of the coastal ocean. Impacts of ocean pollution should therefore be analyzed on a scale that includes both disposal sites and other areas (Goldberg 1975).

The first steps in monitoring include identifying the substances to be measured, the methods to be used in laboratory and field, the sampling program and design, the time interval for sampling and the extent to which beyond-site (farfield) monitoring is appropriate. It may prove that some types of wastes will require no monitoring while others may require comprehensive and long-term monitoring. Monitoring results should be used to influence treatment processes and waste discharge mechanisms so that minimum impact results.

Most existing sites have been used without careful pre-site survey or planning. Baselines are defined poorly or undefined as in the New York Bight. An exception is the southern California area, where local sanitation districts maintain an active research program through the Southern California Coastal Water Research Project and also through the older programs of the City of Los Angeles. The Hyperion Project of 1955-56 (Los Angeles Department of Public Works 1973) was one of the first pre-site surveys ever made and established a basis of ocean data upon which the later extensive monitoring system was founded (Stevenson et al. 1956). The state of California also sponsored a five-year survey of the oceanography of the southern California shelf which provides at least limited information on natural conditions for later comparison (California State Water Quality Control Board 1965).

Three types of site studies are suggested: (1) baseline surveys to establish pre-disposal conditions (2) use monitoring to assess changes that occur during disposal and (3) post-abandonment studies to assess effects after a site is abandoned. These site surveys aim to provide measures of ambient conditions including seasonal variability and exceptional events, and to detect and assess modification of the environment within the site locale arising from disposal practices. Feedback from use monitoring should also be used to validate the existing criteria and premises upon which site selection and waste disposal control are based. Methods for conducting surveys have been formulated (NAS 1971, NSF 1972, NOAA 1972).

BASELINE SURVEY AND USE MONITORING

An agreed and clearly understood definition of the terms baseline surveys and monitoring surveys is essential. Proposed regulations distinguish between the two on the basis that baseline surveys establish a comprehensive understanding of existing conditions at a proposed or existing dump site, whereas monitoring surveys provide evidence of change or lack of change of conditions over a period of time determined by the disposal period and use of site.

The idea has been advanced that baseline should apply only to conditions before any dumping has occurred. Few, if any locations are pristine. The essential attribute of a baseline survey is that it be representative of conditions in a given place at a particular time, because subsequent measurements of change are meaningless unless the baseline is comprehensive. This concept of a baseline being indicative only of a certain time and place is necessary because it would be difficult or impossible to locate an unaltered coastal environment near any major urban area. In some areas, an adequate baseline may require a decade or more of observation (Isaacs 1969, Chow et al. 1973).

The monitoring survey is a relatively straightforward activity which repeats at selected intervals some critical measurements made initially in the baseline survey which have been determined to be most sensitive to environmental changes induced by the particular wastes. The monitoring survey should serve to provide either early warning of perturbations or evidence of lack of change. Both baseline and monitoring surveys should include "control" sites outside the disposal area and beyond the main influence of the wastes so that changes at the site can be compared against general regional dynamics.

Under the proposed regulations, the federal government will conduct the baseline survey and the users of the site or their agents the monitoring survey. The scientific effectiveness and objectivity of such a relationship must be seriously questioned. Since the scientific work applicable to this problem is not, nor ever will be completely standardized, it is far more efficient to have one organization and preferably the same scientists both establish the baseline and monitor the changes that occur. The objectivity of the monitoring is called in question if the user of the site does the monitoring since he is the individual discharging the waste. Baseline and monitoring surveys for which a sound scientific basis is sought should, as a minimum requirement, be designed on a case-by-case basis with the participation of an independent science advisory group containing individuals familiar with the regional characteristics of the site. To achieve a uniform analysis of the site, all the baseline and use surveys would most logically be directed by EPA rather than the organization using the site for disposal.

Chemical Parameters

Selection of chemical parameters to be monitored should be based on the composition of the waste material. The monitoring program should include determination of the concentrations of the specific critical chemicals in the water column or in the sediment, and in the biota (planktonic and benthic) of the dump and control sites. In the water column, dissolved and particulate concentrations should be determined. In the sediment, the distribution of the substance with depth and between the solids and liquids should be obtained so that post-depositional migration can be evaluated. The location and the frequency of sampling should be based on physical oceanographic characteristics as well as disposal techniques. The analytical techniques have been described for some chemicals (NOAA 1972).

Nutrient monitoring in the disposal site should be limited to times when the greatest impact on water quality is to be expected. Dissolved oxygen, which should be monitored on a continuous basis, is a sensitive indicator of possible deleterious effects brought about by dumping of materials that stimulate biological activity. A continuing monitoring of nutrients in the disposal site would be valuable for determining the effect of dumping activities on nutrient regeneration and biological productivity.

Dumping of synthetic organics should be avoided, but if it is unavoidable, they must be included in baseline and use monitoring. The extent of the survey should be broad enough to cover the region of anticipated detectable chemical perturbations as well as the best practicable control area. Synthetic organics in the water column, at the air-sea interface, in the upper few centimeters of ocean bottom sediments and in benthic organisms inhabiting the discharge area should, if possible, be monitored. Whenever possible, an undisturbed vertical profile should be sought at a few stations using a special sampler such as a box corer. Indicator organisms should be chosen such that specific tissue(s) can be readily excised and isolated from the possibly contaminated sediments often associated with benthic species. In past studies, muscles, liver and gonadal tissues from large crustaceans, molluscs, flatfishes or other benthic animals have provided sufficiently large and uncontaminated samples for determination of baselines for synthetic compounds, as well as for regional comparisons. The species selected must be sufficiently distributed so that they can be routinely collected in satisfactory numbers within a specified size range. Efforts should also be made to determine to what degree sex and season affect the variability of the data. Enough replicates should be provided to allow for statistical analyses.

Once disposal has begun, the synthetic organics in wastes must be monitored sufficiently to characterize both their average concentrations and total emissions in the solid and liquid fractions. Emission-proportioned composite samples should be made available upon request to valid regulatory and environmental research programs, as an absolute condition of discharge. In addition, the monitoring program should encourage, and if necessary support research on other inputs of synthetics which would reach the disposal site and interfere with evaluation of monitoring data.

Methods of collecting and procedures for analyzing petroleum hydrocarbons dissolved in sea water are complex. The present data base may be inadequate to set up criteria based on concentrations observed in the biota. The requirements of the disposal area monitoring program should include, on a seasonal basis: measurement of types and amounts of natural aliphatic and aromatic hydrocarbons in the water column; analysis of neuston; analysis of benthic organisms; and analysis of sediments. Analysis of the water column or of nekton would probably not be warranted unless the source and history of the water mass or organisms being sampled were known. This is usually not the case. Gas chromatographic procedures for the analysis of hydrocarbons such as those described by Farrington et al. (1972) would probably be most useful in the program.

In the water column, measurement of alkalinity and pH (an expression of acidity equal to the logarithm of the reciprocal of hydrogen ion concentration) should be required only in areas where highly acid or highly alkaline liquid wastes are discharged. Measurements of the pH of deposited dump materials and interstitial waters would be useful to predict equilibrium species and to assess the probable changes in chemical state and the important transport processes out of the dump material.

The water-to-air transfer of particulate material from a dump site is not monitored at present. As this transfer may present a human health problem, we recommend that, prior to disposal, samples of the near-surface aerosol should be collected for analysis of organic material and viable organisms. During the disposal operation, samples should be collected especially during turbulent conditions or when bubble-breaking processes are operating. These samples should be collected downwind of the disposal site. The difference between the two sets of samples will provide data to assess the potential health hazard.

Physical Parameters

Physical oceanographic site monitoring for near and far fields, and for general circulation will be required, with surveys frequent enough adequate to characterize the main seasonal shifts. In some areas, this may be accomplished on a quarterly basis; in other, more complex areas such as those at climatic zone boundaries, or those in areas of strong circulation, more frequent surveys and closer sample spacing may be required. These more comprehensive surveys should be related to older surveys to extend the time period of measurements.

Surface wind wave conditions, prevailing versus storm, and internal wave conditions must be examined since these generate surges in waters of the shelf and nearshore zones which are the principal agents in substrate movement. Tidal currents will be important in estuaries and in confined embayments where the tidal wave is amplified. Long-term records will be required for these factors. The recording of water motions in areas of strong wave effects will be a technical problem. Frequency and duration of samples for recording meters will be critical due to the potential bias introduced in shallow water where waves are an important energy input.

For outfalls, diffusion from point sources will be a major problem for study. Thermal inputs are also of considerable local importance in these instances. The large effects on local circulation of thermal input from effluents in Santa Monica Bay, California provide an example (Stevenson et al. 1956).

Geological Parameters

The ultimate goal of the physical monitoring studies will be the refinement of suitable predictive methods for anticipating the rates of diffusion of wastes and for defining those conditions which will cause their suspension. Analyses of sand, silt, and clay transport in the framework of the contemporary local sedimentary patterns and processes is the basis of geological monitoring. The basic requirement for adequate geological surveys is direct quantitative sampling which provides ground truth for remote techniques in a sampling network that adequately incorporates natural variability without excessive ship or sample analysis time. Station sampling should be planned jointly with physical oceanography, chemistry, and biology programs. A fundamental reconnaissance strategy should be regional investigations with station and line spacing on the order of tens of kilometers. Alteration of this scale which will occur as characteristics of the specific area become known will effectively create a detailed study.

A substrate inventory defines the quantity of sediment on the sea floor, its physical description and the mode of its delivery, and derives the long term patterns of the net transport of sediment from the textural and deposit geometry trends. After introduction of solids has begun, it is necessary to establish the character of the newly-added sediment since natural and artificial processes of fractionation may segregate the introduced material. Sedimentary studies should include: grab samples, cores, and bottom-actuated photography.

Sand transport monitoring studies should be undertaken in areas of detailed study. Estimates may be obtained by applying equations relating bedload or total load discharge to bottom flow strength as measured by in situ recording current meters. Existing equations for estimating sand transport are empirical, and are valid only for the shallow, quasi-steady flows of the laboratory flumes from which they were derived. For analysis of seasonal variations, the meters should be installed for at least a month at a time in each season. The calculations may be refined by means of independent observations by sediment traps, and by radioisotope labeled sand for mass-balance calculations. Rates of aggradation and degradation on the sea floor, photography, and planting stake fields (Ingle and Gorsline 1973) provide additional checks on the equations. On continental shelves, sand may move only in response to flows associated with the passage of the tidal wave where tide range is large, and in response to flows associated with storm systems. Except in wave-dominated areas, such as the inner shelf depths less than 20 to 30 meters (Swift 1974) the sea floor is often quiescent between peak flow events (Gorsline and Grant 1972).

Gravity transport of coarse and fine materials deposited on the slope and in submarine canyons by turbidity currents or mass movements is common. Such flows are probably much more frequent on Pacific margins than in the Atlantic (Shepard and Dill 1966). It is conceivable that fine materials carried by a turbidity current will travel hundreds of kilometers or that the deposit from a flow may cover thousands of square kilometers of sea floor (Kuenen 1964).

When silt and clay are suspended by peak flow events, they continue in suspension for days or weeks (McCave 1971). They may travel as a near-bottom turbid layer (nepheloid layer) undergoing continual resuspension by wave surges (Drake et al. 1972) and, on the Atlantic Continental Shelf, can be transported to and deposited in the estuaries and lagoons (Meade 1969). On the Pacific shelf, where this process may not operate because of the small number of estuaries, off-shelf transport may be more important (Drake and Gorsline 1973).

There should be periodic observations of concentration, size, composition, and state of aggregation of suspended matter throughout the water column at the proposed disposal site. Suspended sediment concentration gradients vary, in the same way as they do off major rivers, from gentle to rapid lateral and vertical changes. Concentration, monitored optically by means of nephelometry or by filtration; size, established by electronic techniques; and composition by microphotography and chemical analysis in samples incorporating storm variations are the basis of regional mass balance assessment in conjunction with water circulation calculations.

Off the continental slope, a variety of oceanographic conditions exist that will produce unique responses to the disposal of fine sediments. For example, over the Atlantic margin of the U.S., suspended material disposed on Blake Plateau will be rapidly transported to the north by the Gulf Stream. Thus, the monitoring network should be biased to the north of disposal sites in that region. Conversely, over the continental rise of the entire Atlantic Coast, significant and consistent bottom currents flow south (Emery and Uchupi 1972) paralleling the depth contours. Thus, in those depths (approximately 2000 meters) monitoring should be biased to the south.

Biological Parameters

The impact of wastes on the biological communities is the important consideration in regulating ocean disposal. Three types of research study can be conducted to evaluate the effects of disposal: baseline and monitoring studies to detect changes in biological structure and function; bioassays to measure short and long-term effects on organisms; and bioaccumulation studies to quantify the uptake and accumulation of specific elements on compounds by organisms residing at the disposal site. The applications of these types of study at specific disposal sites depend on a variety of factors. The progressive, non-seasonal, changes in composition or numbers of pelagic, demersal, or benthic biota at or near the disposal site are important when these changes can be attributed to the effects of wastes dumped at the site. The accumulation of toxic or undesirable compounds by organisms at the disposal site should be measured especially in animals used as human food. In addition, the pathological effects on marine organisms, including increased incidence of diseases such as fin rot of fishes are indicative of environmental degradation.

Biological effects can be approximated through laboratory and in situ bioassays. These are especially appropriate for long-term exposures of benthic organisms. Changes in growth, behavior, reproduction, productivity, pathology and mutagens are indications of biological responses. Bioaccumulation of compounds by exposed organisms is another estimate of the impact of pollutants on organisms and their food webs.

POST-ABANDONMENT MONITORING

A program of post-use monitoring should be a part of the abandonment process. The important object will be to determine the rate of the site's return to pre-site use condition. In some instances, this return will not occur, for example when a depression has been filled by contained wastes.

Post-use monitoring should be done in the same fashion as the monitoring surveys conducted during site use. Post-use surveys can be time spaced over a period of years, beginning with quarterly survey periods for the first year after abandonment, then semi-annual surveys for one or more years as, terminating with annual surveys for one or more years seems appropriate in relation to the results of the initial and secondary phase interpretations. The post-use surveys should be for a minimum period of three years.

For sites with predictable capacities, a partial abandonment or progressive restriction of use may be worthwhile strategy. Where the site has been mismanaged and its capacity temporarily exceeded, the abandonment will probably be for a finite term and the site may subsequently come back into active use. Several designs are possible and the post-use survey requirements should be flexible to fit the mode selected.

SUMMARY

Baseline surveys and monitoring surveys for ocean disposal operations are fundamental to adequate control. Baseline surveys, registering the state of the marine environment at a particular time and place, do not record pristine environmental conditions. Rather, they provide reference conditions to which future changes may be compared in the course of monitoring surveys which comprise the necessary repetitive measurements sensitive to environmental change.

Among the numerous possible environmental parameters to monitor, a few in the subdisciplines of oceanography warrant emphasis. First, there are four chemical parameters to evaluate: nutrients, metals, synthetic organics, and hydrocarbons. While the last two should not be disposed in the marine environment, they will inevitably enter as trace contaminants in disposal operations and, because of their potential for harm, they require close attention. Second, near-surface aerosols should be analyzed for organic material and viable organisms in case water-to-air transport should become a health hazard. Third, the physical oceanographic assessment should include both near and far-field dispersion as well as general circulation monitoring. Fourth, current-driven and gravity-driven sediment transport processes for sand, silt, and clay in the shelf-slope region should be the basis of geological monitoring. Special emphasis should be placed on regional mass balance assessments for suspended sediments. Finally, the biological structure and function of communities, bioassay, and bioaccumulation should be fundamental to baseline and monitoring surveys.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

Throughout our analysis, the limitations of scientific knowledge about basic ocean processes and their effects on wastes disposed in the marine environment have severely restricted our ability to give definite answers to pressing questions.

These limitations of scientific knowledge have unfortunately led to the use of insufficiently supported criteria in the administration of the permit program for ocean dumping. Without improved understanding of basic ocean processes and the man-induced perturbations upon them, the Environmental Protection Agency will be increasingly faced with disputes arising from scientific uncertainties.

> In our opinion, therefore, it is in the interest of all concerned to consider increased research directed specifically toward reducing the scientific uncertainties associated with ocean disposal. The results of such research could benefit the Environmental Protection Agency by forestalling or mitigating dispute.

The specific research areas we consider most in need of attention are described in detail in Appendix B; they include: dispersion; bioassay; air-sea interactions; environmental effects at and reclamation of existing sites; chemical processes associated with synthetic organics, petroleum hydrocarbons and sulfides; geotechnical studies and geologic hazards; and the effects of rare events.

Although the lack of the necessary detailed scientific data has precluded definite recommendations in some areas discussed in the report, each chapter contains findings and conclusions which form the basis for recommended actions that might improve the capabilities of the Environmental Protection Agency to carry out its administrative responsibilities.

Legislative Background

Chapter I's description of the basic legislation demonstrates that Congress has restricted some major options for consistent regulation. One example of this is the sharing of responsibility for dredged material by the U.S. Army Corps of Engineers and the Environmental Protection Agency. The U.S. Army Corps of Engineers has a dual role as an action agency responsible for dredging and disposal operations, and as a regulatory agency with some authority over the disposal of dredge spoils. This arrangement endangers the effectiveness of the control exercised by the Corps and is a potential source of conflict between the Corps and EPA over regulation of polluted spoil disposal.

> To resolve this problem management of waste disposal in estuaries, coastal waters, and the ocean should be the sole responsibility of the regulatory agency - The Environmental Protection Agency.

Ocean Disposal Materials

In Chapter II we saw that adequate records of amounts, types, locations, and properties with consistent results are not readily available. Uniform estimation methods for determining amounts of disposed materials and clear tabulations made promptly available to the public are essential. Controlling amounts of materials alone is not sufficient to solve the problem, because the properties of the materials themselves can also be significant.

> Every possible effort must be made to limit or to prevent the entry into the ocean of known or suspected dangerously toxic materials, such as certain halogenated hydrocarbons, plutonium, carcinogens, teratogens, mutagens, and materials in certain reactive states.

This will require the development and verification of new analytical techniques including bioassays and the continued identification and regulation of new toxic materials before actual disposal. The decision made by the Congress to exclude some of these more toxic materials has resulted in a significant reduction in environmental risk. Additional exclusions should be pursued by the Agency through its regulatory programs.

Physical and chemical properties of the constituents (sand, sewage solids, glass, etc.) of waste classes (rubble, sewage sludge, chemicals, etc.) are a basis for evaluating their effects on the marine environment. The chemistry of wastes themselves and the effects of that waste chemistry on the environment are related to a series of chemical elements or compounds which require special consideration. They include: trace metals, nutrients, biologically active materials, synthetic organic compounds, petroleum, hydrogen sulfide, and methane. Exotic and persistent synthetic organic materials present a serious potential hazard to the environment. We do not have adequate analytical capability, production and use data, laboratory standards, or predictive capability to deal effectively with the proposed introduction of these materials.

Therefore, where possible, the flux of these chemicals from origin to disposal should be carefully controlled. In addition, work on the development of analytical capabilities should be supported.

Processes Affecting the Distribution and Fate of Materials

Physical, geological, chemical, and biological processes are described in Chapter III. They provide a basis for understanding the fate and effects of disposed materials in the marine environment.

Both the density and velocity fields of the water column must be adequately known in an area considered for ocean disposal. The additional physical information should include meteorological variability, internal waves, momentum and mass mixing coefficients, currents, and waves. Sedimentation processes may be summarized by considering the balance of sediment loss in the different grain sizes for different geomorphologic units (shelf basin, canyon, slope, etc.) The better the balance between erosion and deposition of specific grain sizes is known, the more accurately one may predict the fate of analogous particulates from the wastes that move on or near the bottom. On that basis, very nearshore sites, trenches, and canyons should be avoided for the disposal of most wastes.

Chemical processes at or near the point of waste introduction can change the physical or chemical state of the material. These processes include oxidation, concentration of soluble organics, chelation of metals, solvation reactions, biochemical changes including respiration, sulfate, and nitrate reduction. Redox profiles in sediments provide predictive bases for determining the transformation and release of heavy metals, a chemical process with considerable potential impact.

Biological processes at a potential site must be known well enough to characterize their species composition, population dynamics, temporal variations, and migratory patterns of resident species. Biological accumulation of wastes which may cause either an acute or a chronic effect is a primary biological process to consider.

Bioaccumulation and other stresses on the ecosystem are measured through bioassays which should include any test that demonstrates biological response on a series of appropriate organisms. Assessment of biological impact must consider specific attributes of the organism, waste, and site being evaluated.

Scientific and Technical Bases for Management Alternatives

Appropriate courses of regulatory action may be evaluated by considering general management alternatives available and the scientific and technical limitations imposed on them by this specific problem as is discussed in Chapter IV. Two general categories of waste-related abatement strategies are (1) processes introduced prior to disposal: recovery, reuse, treatment, product modification, and process change, and (2) processes that occur during or after disposal: dispersion, dilution, detention, and diversion.

> Because we recognize that it may not prove feasible to eliminate ocean disposal of sewage sludges and dredge spoils, we recommend minimization of the entry of toxic trace contaminants into city sanitation systems and increased waste and sludge treatment to reduce the deleterious impact of the disposed material on marine organisms and to diminish the risk to humans.

During and after disposal, engineering design may be used to alter waste fields or their mobility. In this context,

> some materials might best be contained in the sea bottom through burial while others should be dispersed and assimilated by the environment.

Analysis of abatement strategies or engineering opportunities must include consideration of the limitations on scientific knowledge in this area.

> Therefore, a decision method which explicitly recognizes inherent scientific uncertainties must be adopted. The assumed adequacy of the available information represents an important characteristic of the decision process.

The significant lack of this information in the case of ocean disposal means that any decision to use the marine environment as a waste receptacle entails a degree of risk which may be unacceptable to some segments of the society.

Incorporation of the waste-related abatement strategies in a decision method that recognizes scientific uncertainties may be realized in management systems that (1) regulate ambient environmental quality, (2) regulate effluents, or (3) tax effluents. The existing criteria and monitoring used by the Environmental Protection Agency are concerned primarily with the regulation of effluents. Environmental criteria and effluent criteria act in absence of definitive scientific information as an intermediary between the pressure to discharge waste and the legislative mandate to protect the environment.

The criteria will be attacked because of their specified role as a device for mediation. The EPA should document and make publicly available the rationale on which specific criteria are based.

The rationale should include basic data, test methods, literature references, and any alternatives that were considered. It should be a complete and open statement about what was known about the topic at the time the criteria were selected. Such documentation will preserve the effort that went into criteria selection, defend the rationale used, and serve to identify areas of research that could improve the criteria.

Since the number of formal permit applications is small, the EPA should document at least in important cases, and make publicly available the rationale behind any denials of permit applications.

This documentation would supplement the published general criteria and provide prospective applicants for permits with a better understanding of how the regional EPA administrator is arriving at his decisions.

While environmental and effluent criteria are an important basis of the existing system, their limitations must be clearly spelled out.

Criteria do not protect against unknown chronic effects. Existing criteria and monitoring systems assume that environmental damage will be (1) reversible and (2) not catastrophic. There is no assurance that these assumptions are correct.

Indeed, chronic pollution leading to irreversible and possibly catastrophic damage remains as one of the most perplexing questions in this and many other environmental problems.

The necessity for some waste-handling systems, even with our presently limited knowledge about effects, is the basis for objectives that a management strategy can attempt to achieve.

It should: confine disposal; exclude wastes with unknown effects; avoid an irreversible dependence on the ocean; exlude wastes that concentrate in food webs; control the rate of disposal in order to avoid overloading site capacity; continually re-evaluate effectiveness of management, and develop new knowledge as necessary.

Site Selection

Site selection, discussed in Chapter V, is a part of the program in which the EPA has only recently become active, because most sites in current use were chosen before the Agency's jurisdiction in this area.

> Timely baseline and monitoring studies of current and proposed ocean disposal sites are essential. No disposal site should be abandoned in favor of a new site until field data evaluation demonstrates that the new site is less objectionable from an environmental standpoint than the old site.

Such evaluation must adequately describe seasonal variation which will usually require data gathered for at least a year.

Chemical changes resulting from ocean disposal are primary considerations for disposal site selection. The composition of the material being dumped is of initial interest only.

> The crucial issue for site selection is the transient, steady state, and long-term chemical changes brought about on the site and its surroundings and the biological effects of these changes.

To evaluate this ultimate question, a description of the waste should determine whether dispersal or containment in the environment is most desirable. With this goal in mind, the characteristics of potential sites may then be evaluated through predictive analyses of dispersion and biological effects. The prediction of potential biological effects is often attempted by qualitative analogy with previous discharges and their effects. The prediction of dispersion may largely be determined by models of nearshore physical oceanographic processes.

Site selection should also be conditioned by the degree of control that can reasonably be exerted during site use.

> Regulatory procedures should assure that disposal occurs only within designated areas, and that the quality of the disposed material conforms to the permit.

Measured waste dispersion compared to predicted dispersion (mass balance) initial mixing zone, and dispersion concentrations, should be explicitly included as part of the monitoring program.

> Data supporting the deep sea as a site for waste disposal are lacking; therefore, extreme caution must be applied to any but the most innocuous use of the area.

Once a site has been selected or is in use its capacity, which will be a fixed total amount for contained wastes or a maximum rate of introduction for dispersed wastes, must be considered. Abandonment may become necessary due to overloading, physical limitations, legislative change, advances in waste control, or changes in the value of the site for other uses.

Site Monitoring

Chapter VI discusses the monitoring of specific geographic areas that have been chosen as sites for disposal. However, such site-specific monitoring should not ignore the potential for broad-scale chronic pollution of the coastal ocean which could become, if undetected, a far more serious threat than the degradation of restricted areas.

Therefore, monitoring in areas away from specific sites is necessary.

Under the proposed monitoring regulations, the federal government conducts the baseline survey and the permittees or their agents conduct the monitoring survey.

In order to make the scientific evaluation more effective and to reduce the potential for bias, EPA involvement should extend from baseline surveys to active participation in the monitoring phase. The details of each survey will have to be specified on a case-by-case basis and should be reviewed by an independent science advisory group.

This independent scientific review procedure should be established to aid EPA in making scientific reviews of ocean disposal problems on a regional basis. Independently selected panels should review plans for obtaining field data in site selection, evaluation, and monitoring.

To aid in the monitoring of nutrients, synthetic organics, and other critical chemical compounds, it is vital that emission-proportioned composite samples be made available to valid regulatory and environmental research programs upon request, as an absolute condition of discharge.

The criteria concerning disposal of wastes should specifically require appropriate information about the chemical and physical properties of waste materials proposed for ocean disposal. In addition, provisions should be made in the criteria and regulations for requiring studies and research to provide needed data not currently available.

Monitoring must incorporate a large number of factors which include: alkalinity, pH, water-to-air transfer, winds, wind-driven circulation, density-driven circulation, diffusion processes, sedimentation processes, suspended sediments, indigenous species, community structure, and other factors. Monitoring of these aspects should continue after the site is abandoned to ascertain leakage, transport, or transformation of chemicals from the waste deposits which could impede biological recolonization and restoration.

When such impedance is determined, reclamation procedures may be required.

APPENDIX A

RESEARCH RECOMMENDATIONS

1. Dispersion

Dispersion processes, although poorly understood in the coastal marine environment, are the basis for physical prediction of the fate of disposed materials. Therefore, research should be aimed at understanding the processes which govern the transport and dispersion of both suspended and dissolved waste material over both short and long spatial and temporal scales. Assessment of effects requires comprehensive physical oceanographic knowledge to determine the location and concentration of waste material.

Increased basic research is essential to develop and refine better models of physical and geological processes for controlling far-field pollutant transport and dispersion. Significant improvement in models will depend on analysis and synthesis of new, well-designed shelf-slope experiments. Emphasis in theoretical circulation studies should be on improvement of our understanding of the fundamental processes and causes of circulation and, consequently, of the transport of disposed materials. Such problems as the nature of the transient response of the ocean to storms or other atmospheric events, the factors which control the mean and variance of the circulation, the nature of slope-shelf and shelf-nearshore interaction, and the coupling of shelf and slope waters remain inadequately understood, yet all have basic implications for waste disposal.

We stress the need for site-specific baseline monitoring surveys to assess adequately the dispersion characteristics of different waste materials on the continental shelf. These surveys have not yet been made and the development of adequate far-field models must await such assessment. The results of such studies as the MESA New York Bight project can be expected to contribute significantly to our understanding of shelf processes. General knowledge of shelf processes is not sufficient to describe any specific local area. Site-specific physical oceanographic field studies are essential at current and proposed dump sites. These studies must comprehensively incorporate spatial and temporal variations in physical oceanographic processes so that decisions concerning specific sites can be made. It is also important to conduct special studies of prototype regions of particular interest, such as regions in and near submarine canyons and banks, deep oceanic trenches, and coastal areas of high freshwater discharge.

Bedload sediment transport processes are directly related to near-bottom circulation patterns and wave effects, and apply to particulate wastes of hydraulic equivalence to sands. Natural sediment fluxes, bedload dynamics, mass balances, origin and development of bedforms, rates and processes of erosion and deposition of particulates, and flow due to turbidity currents are examples of substrate processes for which we have some qualitative ideas and data at shelf depths but not enough information for useful quantitative prediction (Bagnold and Inman 1963, Middleton 1965, Swift et al. 1972, Hampton 1972). These are some of the least well-known factors affecting decisions about deep-water disposal.

Development of new observational technology and capability for surface and very near (millimeters to centimeters) surface processes is basic to the understanding of the transport of floatables. Technology should be developed for making near-surface Eulerian current measurements, and dye dispersion technology adequate for accurate tracking of released dye is essential.

A comprehensive knowledge of the mode of release of the particulates to the water column is prerequisite to the development of a more complete understanding of the dispersion and transport of particulate wastes. Release may be via diffusers on an outfall or by a variety of dumping methods from barges or ships. Among other methods and techniques worth pursuing is tracing or photographing the actual release from above and within the water column. In any event, knowledge of the sediment (particulate) dispersion during dumping or discharge operations in both shallow and deep water (from shelf to slope to deep ocean) is essential.

An important aspect of the development, refinement, and verification of near-field and far-field physical dispersion models is the review and exchange of data among all sectors of the research community.

2. Bioassay

The basis of concern about dumping waste in the ocean is its effect on the marine environment, particularly on marine organisms. Techniques must be developed for the culture and manipulation of marine organisms under a variety of test conditions to assess probable biological impacts of wastes. Bioassay techniques should be developed for "standard" or "reference" organisms (such as _Acartia_, _Engraulis_ _prolarvae_, certain polychaetes and others) that are more typical of and sensitive to the local marine environment than the "weed" species (such as _Artemia_ or _Fundulus_). Bioassays on standard species should be compared with those on indigenous and tolerant species.

Further research is required to relate laboratory acute toxicity levels to near and far-field dispersion models, in order to determine predictive ranges around disposal sites for a given pollutant. Where possible, in situ bioassay tests should be made and compared to laboratory results. Thus, bioassays should be developed to detect long-term as well as short-term impacts.

3. Air-Sea Interactions

Scientific concern about atmospheric transport of surface active wastes is growing. Although there is no firm evidence to date that sea-to-air transport of microbial and other organic-laden particles downwind of a dump site or sewage outfall is hazardous to human health, the potential for this hazard exists. Because so little is known about the sea-to-air transport and concentration of these materials, research studies must be carried out before the potential hazard can be evaluated. Studies should be made of: microbes in the air at dump sites; interactions of surface films with microbes; transport of harmful substances from sea to air; influences of slicks on aerosols; and the collection efficiency of bubbles rising through the water.

In addition, there is need for a surface description and measurement criterion based on examination of the surface water microlayer and also, possibly, of the millimeter surface layer. The traditional analyses for hexane extractables and floatables may still be useful in determining an aesthetic criterion, but they are inadequate for monitoring the ecological processes and effects and interactions of trace materials, both organic and inorganic.

New methodology should employ infrared identification and estimation of the content of synthetics and other organics in slicks. Trace metals can be identified and estimated by neutron activation analysis or other trace element procedures. Estimation of microbiological populations in the microlayer is also feasible.

4. Synthetic Organic Compounds and Petroleum Hydrocarbons

Research on the effects of synthetic compounds on natural biological communities is essential. Studies should be made of toxic and chronic effects of these compounds on organisms, their pathways in the natural environment, their storage and residence times, processes whereby they are altered, and the toxic effects produced by the alterations.

Primary research should investige sublethal chronic effects of aliphatic and aromatic hydrocarbons and rates and products of microbial degradation of petroleum at in situ conditions. Generally, improved analytical methods are needed, particularly for aromatics.

Secondary needs include improved criteria for distinguishing petroleum hydrocarbons from recently biosynthesized hydrocarbons. Biological pathways of petroleum hydrocarbons in the food chain must be discovered, and we need to know more about the marine distribution of low molecular weight hydrocarbons.

5. Environmental Effects at Existing Sites

The most valuable criteria for the establishment of future dump sites can be obtained from monitoring current disposal operations. In situ chemical and biological studies of existing disposal sites at locations environmentally similar to proposed sites are a variation on such monitoring. This kind of experiment can answer specific questions about biological impacts associated with known levels of dumping at sites that are environmentally similar and can provide information on such factors as dimension, time scales, and surface-to-volume ratios which are realistic and not scaled to laboratory dimensions.

It would be particularly valuable to correlate biological community structure, species diversity, and species numbers with geological setting and chemical changes within the water column or sediment surface. Studies of the benthos would provide needed information on such important questions as: Can the levels of heavy metals or chlorinated hydrocarbons in the sediment be related to changes in the population number or structure of organisms? Can species diversity be related to readily observable chemical properties of the sediment-water interface, sediments, or pore waters?

Abandoned disposal sites should be studied to determine long-term chemical transformations and transport of waste materials, and rates of natural and artificial recolonization and restoration.

6. Disposal Site Reclamation Techniques

Wastes have often been widely dispersed in the ocean at locations where the deposits have created environmental or aesthetic problems after the disposal sites have been abandoned. Therefore, research and development in reclamation technology is urgently needed. Possible approaches include: capping polluted material; aerating anaerobic systems to enhance biodegradation and other forms of mobilization; and investigating natural and artificial reclamation rates and processes (as, for example, in recolonization).

7. Genesis and Decay of Sulfides

Information is needed on the formation of free sulfides in marine sediments. Hydrogen sulfide formation probably has the most significant toxicological impact for the benthic communities. Areas for investigation should include: rates of release of substances to the water from sediments and from various compacted waste materials; association of metals with particles in liquids and chelates; rates of introduction of sulfides into the water and their persistence; effects of changes in redox potential on other aspects of the marine environment; and immediate and long term oxygen demands of sediments.

8. Geotechnical Studies and Geologic Hazards

Information is needed on the engineering properties of natural substrates and waste deposits. Rapid loading of fine-grained waste deposits with high-water contents can cause mobilization of substrates, releasing particulates into the water column. Elastic moduli of waste material and of natural substrates are needed to understand and predict the behavior of substrates and sea floor during the passage of seismic waves. This is particularly important for outfall design in the tectonically active areas of the Pacific Coast and parts of Alaska.

9. Effects of Rare Events

Rare events, such as the flood or storm of the decade or century, may be the most important elements to examine in understanding changes in sea floor morphologies or the movement of deposits. Since these events can be frequent compared to the life of disposal sites (probably several decades), study of these extremes is of primary importance. The influence of such events is greatest on low- to moderate-energy shelves and coasts, such as the East Coast and Gulf of Mexico areas, and probably least important on the northern Pacific Coast. Predictions of sediment motion or water circulation based on short term "prevailing" conditions will lead to serious errors in long-term extrapolations for most coastal sites, and may also prove to be deceptive in deep-water sites where transient conditions of high energy can also occur.

APPENDIX B

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